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Value of food provisioning ecosystem services in the Northeast Atlantic

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Abstract

Lack of scientific knowledge of how marine ecosystems relate to each other, how they are producing services and how to quantify ecosystem flows at adequate accuracy, have led to a situation where marine ecosystems are undervalued or even completely ignored in decision-making process. More research is needed from the value of marine ecosystem services in order to better integrate them into decision-making. Seafood production is essential part of the marine provisioning services and the aim of this study is to estimate the potential value of the European Union's seafood production in the Northeast Atlantic (FAO fishing area 27).

Fish stocks are currently managed too short-sightedly in EU and for that reason, EU is unable to take full advantage of the true potential of the stocks. This study provides quantitative analysis of the potential benefits of the rebuilt fish stocks in the Northeast Atlantic for the EU. Growth potential of EU's wild capture production in Northeast Atlantic were calculated by comparing current production and theoretical maximal production, where all fish stocks could provide Maximum Sustainable Yield (MSY) at the same time. Besides quantifying potential value of EU landings in Northeast Atlantic, this study also compares different rebuilding pathways to achieve collective MSY.

According to the result of this study, EU fishing fleet would get €4.43 billion more annual profit if every stock in the Northeast Atlantic could produce MSY. In order fish stocks to produce MSY, the long-term effort level of EU fleet should be dropped by 38%. Total revenue of fishing is maximised when stocks are harvested to a level of Maximum Economic Yield (MEY), where annual profit would be €4.64 billion more than currently while long-term effort level should be dropped by 48%.

In this study, several management strategies for rebuilding the Northeast Atlantic stocks were compared, and rebuilding time and net present value were calculated for each management strategy. The results address that it is preferable to decrease effort level as soon as possible to match the effort level of MSY or MEY. The sooner the optimum effort level is reached, the shorter is the rebuilding time and the higher is the net present value.

Keywords
Fisheries economics, rebuilding fish stocks, Gordon-Schaefer model, valuation of provisioning ecosystem service

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Tiivistelmä

Tutkitun tiedon puute meriekosysteemien suhteesta toisiinsa, kuinka ne tuottavat ekosysteemipalveluja ja kuinka arvottaa niistä saatavia hyötyjä tarpeeksi tarkasti, on johtanut tilanteeseen, missä meriekosysteemien arvo päätöksentekoprosessissa on alimitoitettu tai jopa täysin sivuutettu. Arvottamistutkimusta meren ekosysteemipalveluista tulisi lisätä, jotta ne kyettäisiin ottamaan paremmin huomioon päätöksenteossa. Merenelävät ovat olennainen osa merestä saatavia ekosysteemipalveluja ja tämän tutkimuksen tavoitteena on arvioida Euroopan unionin merenelävätuotannon potentiaalinen arvo Koillis-Atlantilla (FAO kalastusalue 27).

Nykyisin EU hallinnoi kalakantojaan liian lyhytnäköisesti, jonka takia se ei kykene hyödyntämään merenelävätuotannon koko potentiaalia. Tämä tutkimus tarjoaa kvantitatiivisen analyysin Koillis-Atlantin uudelleenrakennettujen kalakantojen mahdollisista hyödyistä Euroopan unionille. EU:n kalansaaliin kasvupotentiaali Koillis-Atlantilla laskettiin vertaamalla nykyistä tuotantoa teoreettiseen maksimituotantoon, joka saataisiin, kun kaikki kalakannat olisivat suurimman kestävän tuoton tasolla samanaikaisesti. Koillis-Atlantin kalansaaliin potentiaalisen arvon määrittämisen lisäksi, tämä tutkimus vertaa eri uudelleenrakentamisvaihtoehtoja kollektiivisen enimmäistuotannon saavuttamiseksi.

Tulosten perusteella EU:n kalastusalusten vuotuinen voitto kasvaisi 4.43 miljardia euroa jos kaikki Koillis-Atlantin kalakannat kykenisivät saavuttamaan suurimman kestävän tuoton tason. EU:n kalastusalusten tulisi vähentää pitkänaikavälin kalastuspanosta 38 prosenttia, jotta suurimman kestävän tuoton taso olisi mahdollista saavuttaa. Kalastuksesta saatava voitto olisi suurimmillaan, jos kalakannat saalistettaisiin suurimman kestävän taloudellisen tuoton tasolle, jolloin vuotuiset voitot kasvaisivat 4.64 miljardia euroa nykyisestä ja pitkänaikavälin kalastuspanos laskisi 48 prosenttia nykyisestä.

Tutkimuksessa vertailtiin useampia vaihtoehtoja Koillis-Atlantin kalakantojen uudelleenrakentamiseksi ja kaikille vaihtoehtoisille poluille laskettiin uudelleenrakentamisaika sekä nettonykyarvo. Tulosten perusteella on suositeltavaa laskea kalastuspanos mahdollisimman nopeasti vastaamaan suurinta kestävää tuottoa tai vaihtoehtoisesti suurinta kestävää taloudellista tuottoa. Mitä nopeammin optimaalinen kalastuspanos saavutetaan, sitä lyhyempi on uudelleenrakentamisaika ja suurempi on nettonykyarvo.

Avainsanat

Kalatalous, kalakantojen elvyttäminen, Gordon-Schaefer -malli, ekosysteemipalveluiden arvottaminen

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Muita tietoja

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1 Introduction

Importance of the ocean cannot be stressed too much, since it covers more than 70% of earth's surface and nearly 50% of planet's entire species are dependent on it (Djavidnia et al., 2014). Ocean includes wide variety of ecosystems, ranging from deep seas to highly productive coastal waters. Oceans maintain life on our planet and offers vital ecosystem services to benefit of us all. Fisheries and aquaculture are an important food and protein source in all over the world, especially in least development countries (FAO, 2018). However, marine ecosystem services are not limited to seafood, albeit it is the most visible part. Marine ecosystems regulate climate by transporting heat from the equator to the poles, they are influencing world's air circulation by producing over half of the world's oxygen and storing 50 times more carbon dioxide than atmosphere. In addition to those, marine ecosystems avert floods, storms and erosions; enables wide range of recreational activities, which bolster tourism; provide raw materials for the use of medical purposes; and support cultural and aesthetic uses - just to name a few. While providing these services, marine ecosystems create business opportunities, which are employing over 4 million people in EU, generating €658 billion of turnover and €180 billion of gross value added in 2017. (European Commission, 2019)

Benefits of the marine ecosystem services are undeniable, and societies are highly dependent on them, but increased human pressure on marine resources has led to a serious concern about the state and health of the marine ecosystems (Halpern et al., 2008). Until 1990s, marine management were operated sectoral but since then, the shift has happened towards a more holistic approach to considering ecosystem services. Management tools with wider perspective were needed, since sectoral approach was not able to reveal the links and relationships between ecological, social and economic systems (Atkins et al., 2011). Ecosystem-based management measures direct and indirect contributions that ecosystems have on human well-being and highlights how different ecosystem services interlinks with each other (de Groot et al., 2010). Millennium Ecosystem Assessment (MEA) (2005) divides ecosystem services into four categories: *provision services*, *regulating services*, *cultural services* and *supporting services*. However, classification by MEA is not the best suited for environmental valuation and accounting, and for that reason several improvements have been introduced to it. The most known attempts for replacing MEA are The Economics of Ecosystems and Biodiversity (TEEB) and the Common International Classification of Ecosystem Services (CICES).

Lately economists have addressed growing interest to ecosystem services and their valuation. Valuation of ecosystem services has been controversial topic ever since Costanza et al. (1997) published their study on the monetary value of the world's ecosystem services. Some scientists argue that valuation can support decision-making process and give attention to the ecosystems that otherwise would go unnoticed (Laurans and Mermet, 2014), while others state that ecosystem services should be valued economically only on very specific circumstances, otherwise valuation studies will only contribute to worse decisions (Spangenberg and Settele, 2016). Ecologists tend to underestimate the need for economic valuation of ecosystem services because in their opinion, nature has an intrinsic value, which makes it irreplaceable, and thus there is no point of giving an economic value to the nature since it should already be above everything else (McCauley, 2006). Ecosystem services are often seen too complex and multi-dimensional to be adequately valued with classical economical tools, where aggregated individual preferences represent values of the whole group (Chee, 2004; Kenter et al., 2016).

Even though economic valuation methods and their purpose remains controversial, still today's decision-making relies heavily on economics, thus the environmental benefits should also be expressed in monetary terms, at least on some part, otherwise they are at risk to be overlooked. Herendeen (1998) captures the same idea in a compact form: "Economics is there first, and all must speak its language seriously, at least some of the time, or be cut out of crucial part of the debate". Of course, decisions should not be based only for economic valuation and therefore marine ecosystem services assessment should cross scientific boundaries in order to achieve satisfying results. As an indication of that, over 400 marine ecosystem service practitioner listed comprehensive integration of economics, natural and social sciences into ecosystem service assessment, as one of today's top research priorities (Rivero and Villasante, 2016).

However, economic valuation has a significant role in decision-making and in the best case, economic valuation provides means and methods to rationalize the process (Laurans and Mermet, 2014). For example, valuation of ecosystem services could shape ecological results to more understandable form for decision-makers and in that way, they could be taken better into account when new policies are determined (Armsworth and Roughgarden, 2001). Economic valuation reveals problems and trade-offs of different management options and enables their comparison, which creates foundation for coherent public policies. Economic valuation also reveals some of the hidden values, which otherwise would go unnoticed. For example, the resource could be largely undervalued, or it may cause externalities (positive or negative) and without proper economic valuation, those market failures would not have such an impact on the project planning (Armsworth and Roughgarden, 2001). Thus, valuation could help to protect ecosystem services by transforming the biological data into more usable form for decision-makers perspective (Laurans and Mermet, 2014).

Humans cause harmful impacts to marine ecosystems and their services for example by overfishing, commercial shipping, nutrient runoff, pollution, climate change and habitat destruction (Halpern et al., 2008). Lack of scientific knowledge about how marine ecosystems relate to each other, how they are producing services and how to quantify ecosystem flows at adequate accuracy, have led to situation where marine ecosystems are undervalued or even completely ignored in decision-making process (Barbier, 2017; Rivero and Villasante, 2016). More research is needed from the value of marine ecosystem services in order to better integrate them into decision-making. Better decisions for marine ecosystems could be made if the quantitative relationship between ecosystem services and their benefits were better understood (Barbier, 2017).

1.1 Aim of the study and used methods

Seafood production is essential part of the marine provisioning services and this study provides a small piece to a larger entity that strives to estimate the value of marine ecosystem services. The aim of this study is to estimate the potential value of the European Union’s seafood production in the Northeast Atlantic (FAO fishing area 27). Marine ecosystem valuation studies aim to fill the knowledge gap by conducting quantitative analysis of the relationship between marine ecosystem services and their benefits.

Fish stocks are currently managed too short-sightedly and because of that, EU is unable to take full advantage of the true potential of the stocks. This study provides quantitative analysis of potential benefits of rebuilt fish stocks. In order to rebuild the stocks, investments must be placed on long-term benefits of the stocks by reducing fishing effort. Because of effort reduction, net profit of the fishing might decrease temporarily but eventually it will lead to higher landings and earnings.

EU fleets are currently operating inefficiently in terms of both catch and profit because of the overexploitation of the stocks. It is possible to increase profitability by reducing fishing effort in order stocks to grow. In the present study, growth potential of EU's wild capture production in Northeast Atlantic were calculated by comparing current production and theoretical maximal production. Theoretical maximum production for the EU's Northeast Atlantic fisheries were determined by assuming that all fish stocks could provide Maximum Sustainable Yield (MSY) at the same time and effort level of the fleet is reduced to a level where catching MSY is possible.

When fishery is managed with MSY, it maximizes the populations of fish stocks but usually economists desire to manage stocks by maximizing economic benefits by maintaining the populations in level where maximum economic yield (MEY) is reached. However, this study primarily looks to manage fishery in a way that stocks can produce MSY, because that is also the objective for the EU Common Fishery Policy (CFP). In the World Summit on Sustainable Development in 2002, EU made a commitment to restore and maintain harvested fish populations to a level, where MSY is produced. Objective was to reach optimal exploitation rates largely in 2015 and for all stocks, no later than 2020 (European Commission, 2013a).

Besides quantifying potential value of EU's landings in Northeast Atlantic, this study also compares different rebuilding pathways to achieve collective MSY. Rebuilding time and net present value were calculated for each pathway. At the final part of the study, estimate is presented of the future's total seafood production in the Northeast

Atlantic, which includes both wild capture and aquaculture production. Four arbitrary annual growth rates were used for estimating the aquaculture production growth in Europe.

This study follows the paper published by Guillen et al. (2016) in order to see at which direction, have the Northeast Atlantic fish stocks developed since their study, and have the EU’s position changed in relation to MSY. To ensure comparable results, method of this study adapts the method of Guillen et al. (2016). Study uses the Gordon-Schaefer bioeconomic model for fisheries management.

The structure of the study is formed as follows. Section 2 discussed subject of ecosystem services, and different models and typologies for ecosystem services are presented. Section 3 provides a review of seafood production and current issues in fisheries. Section 4 addresses method and objective of the study. Results are reported in section 5, discussion and conclusion are in section 6 and 7.

2 Ecosystem services

Nation's wealth generates from four source of capital: manufactured capital (material goods and infrastructure), human capital (knowledge, attitude and skills of the individuals), social capital (trust, norms and institutions) and natural capital (ecosystem services) (World Bank, 2006). Natural capital is providing all the necessary conditions to support life in this planet, so in that sense, it can be seen as the most important form of capital. The terms natural capital and ecosystem services are often mixed together. Ecosystem services are the benefits (e.g. material, energy, intangible) people are receiving from the natural ecosystems and natural capital are the stocks of natural ecosystems (Costanza et al., 1997). For example, fish stock is component of natural capital, while food provisioning is one of the ecosystem services it provides.

Ecosystem services are often referred as links to connect biophysical reality to human socio-economic well-being (TEEB, 2010). Ecosystem services are nature's fundamental structures and without them life in the Earth could not exist, at least as the way we know it. Human's basic needs are mostly provided by the ecosystem services and it is impossible to imagine life without them. Ecosystem services are indispensable, otherwise well-being and health of the people would be in jeopardy. (Millennium Ecosystem Assessment, 2005)

Often ecosystem services are seen only as material goods such as food, fibre or wood. Material centred approach easily overlooks the non-market benefits, even though they are playing a vital role in providing well-being to humans. These non-market ecosystem services are contributing to ensure clean water flow, protect us from flooding and from other natural disasters, like landslides or tsunamis. Ecosystem services provide climate regulation by maintaining world's hydrological cycle and carbon sequestration by absorbing CO_2 from the atmosphere. Thanks to ecosystem services, people have opportunity to enjoy recreational activities and sometimes even form spirituals or religious bonds to landscape which ecosystem services provide. (Haines-Young and Potschin, 2010)

There are a few often quoted and widely accepted definitions of ecosystem services. Westman (1977) was among the firsts to research ecosystem benefits and he suggested that society could make better policy and management decisions by enumerating benefits that ecosystems could potentially provide. Daily (1997) proposed that ecosystem services are “the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life”. Costanza et al. (1997) suggested that “ecosystem functions refer variously to the habitat, biological or system properties or processes of ecosystems, and the ecosystem goods and services represent the benefits human population derive, directly or indirectly, from those ecosystem functions”. The Millennium Ecosystem Assessment (2005) adapted a broader vision by defining ecosystem services as benefits people obtain from the ecosystems. Jax et al. (2013) sums the definitions up by stating that ecosystem processes become ecosystem services only if they contribute somehow to human well-being, either actively or passively.

The concept of ecosystem services is an important tool for linking ecosystems functions to human welfare, and it is highly relevant for decision-makers to be familiar with the links in order to make rational and far-reaching decisions concerning, for example, the use of natural resources (Fisher et al., 2009).

2.1 Classification of ecosystem services

Ecosystem service classifications were originally needed to make the concept of ecosystem services more accurate in order to enable discussions, assessments, modelling and valuation (Costanza et al., 2017). Classifications were needed to better assess the benefits that specific ecosystem service could potentially provide to human well-being. There are a number of different classifications of ecosystem services in the literature that have been developed over the last fifteen years (e.g. MA, 2005; Beaumont et al., 2007; TEEB, 2010; Haines-Young and Potschin, 2012; La Notte et al., 2017; Lillebø et al., 2017) and each has its own benefits and disadvantages (Hattam et al., 2015).

2.1.1 Millennium Ecosystem Assessment

The Millennium Ecosystem Assessment (MEA) (2005) were the first global and comprehensive assessment of the effects of ecosystem services to people's welfare. MEA highlights that human's well-being is maintained by ecosystem services and it shows that ecosystem services are the links between nature`s processes and human welfare (La Notte et al., 2017).

MEA defined ecosystem services as the benefits people obtain from the ecosystems. According to the MEA, the ecosystem services can be divided into four broad categories: provisioning services, cultural services, regulating services and supporting services (see table 1).

Table 1: Categorization of ecosystem services by Millennium Ecosystem Assessment. (MEA, 2005; Costanza et al., 2017)

1) **Provisioning services** are the products directly obtained from the ecosystem. Provisioning service include for example food, timber, fiber and medicine, and their value are usually defined in the market.

2) **Cultural services** are non-material benefits people obtain from the ecosystems. Cultural services include aesthetic value, recreational activity, cultural identity, environmental related religious and spiritual experiences and tourism. For example, benefits that individual is getting from a hunting trip cannot be valued only by the catch, otherwise recreational benefits from a hiking in the forest are overlooked. It is hard to define monetary value for most of the cultural services because they are not market based.

3) **Regulating services** are the benefits ecosystem services offer by regulating ecosystem processes. Maintaining the quality of air and soil, providing flood and disease control and water purification are few examples of regulating services. Often people take regulating services for granted, without even noticing nature's part behind them. True value of the regulating services is recognized, at latest, when performance level of the services is deteriorated.

4) **Supporting services** are needed to produce all other ecosystem services. These types of necessary services are photosynthesis, primary production and nutrient cycling, among many others. Supporting services are affecting to humans indirect by maintaining the processes and functions necessary for provisioning, regulating and cultural service.

Figure 1 illustrates how the four different service categories provide benefits to human well-being. Ecosystem services' different importance level to human well-being are presented by different shade and thickness of the arrows. Supporting service panel is placed in a way that none of the arrows is touching it, so there is no direct link between supporting services and human well-being. However, supporting services are providing benefits to humans through the provisioning, cultural and regulating ecosystem services. (Bouma and van Beukering, 2015)

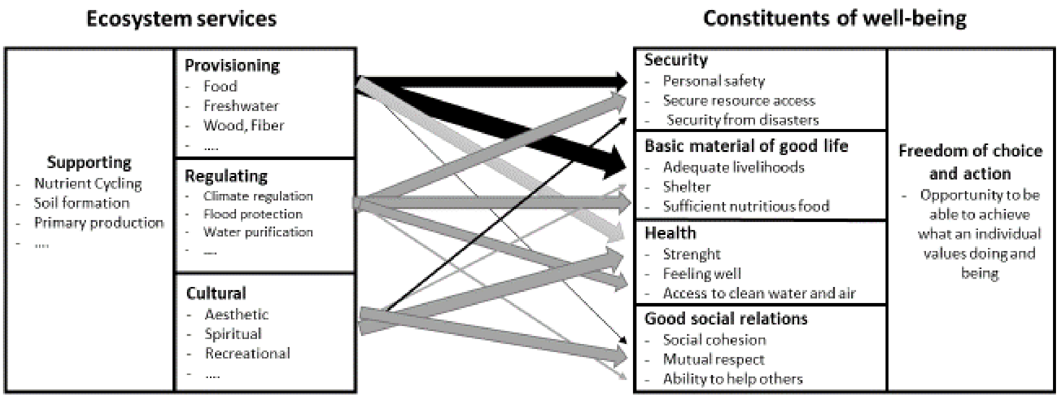

Figure 1: The concept of ecosystem services in millennium ecosystem assessment (adapted from MEA, 2005)

MEA have received much praise and its substantial impact to the ecosystem service research cannot be denied. Although, some shortcomings towards MEA have also been identified in the literature. Biggest shortcoming is related to supporting services, and more specifically distinction between ecosystem functions and ecosystem services. Supporting services are not directly offering any benefits to humans but they are a part of the natural mechanisms and processes that generates ecosystem services for humans. Problem with MEA classification is that it does not draw definite line between the ecosystem functions and ecosystem services. Lack of clear difference between ecosystem function and ecosystem service creates a risk of double counting, since giving a separate value to ecosystem function, would mean that value of that ecosystem function would be counted twice because it is already included in the valuation of ecosystem service (Ledoux and Turner, 2002; Boyd &

Banzhaf, 2007; Fisher et al., 2009). Ecosystem services should be the benefits that people are enjoying, while ecosystem functions should be the ecological processes that enable ecosystem services, and valuation should be given only for the ecosystem services. MEA is not suitable for economic valuation studies because it lacks hierarchy within the classification (Hattam et al., 2015). For example, water purification service is an ecosystem function, which is essential part of the provision service of the groundwater. Double counting occurs if the purification service is first evaluated independently and then second time as a part of the provisioning service of drinking water. MEA does not make clear difference between these two groups and therefore risk of double counting exists. (Haines-Young and Potschin, 2010)

2.1.2 Cascade models

Cascade models were introduced to fix the shortcoming of MEA. De Groot et al. (2010) introduced framework called The Economics of Ecosystems & Biodiversity (TEEB) and Haines-Young and Potschin (2010) introduced their approach, which later was used as a template to a European Environment Agency`s framework called Common International Classification of Ecosystem Services (CICES) (Haines-Young and Potschin, 2012). Both approaches adapt much from the MEA but with a few critical changes they were able to form a more advanced classification model, which were better suited to reality.

Haines-Young and Potschin (2010) modified MEA by excluding support services from the ecosystem services, and then dividing support services into two separate components; *biophysical processes* and *ecosystem functions* (see figure 2). This design makes clear distinction between nature’s ecological functions and ecosystem services. For example, woodland is a biophysical structure, which provide ecosystem functions like biomass production and water retention. Ecosystem functions provides ecosystem services, of which humans are benefiting. In this example case, ecosystem services, which are provided by the ecosystem functions, are for example flood protection and harvestable biomasses. (Haines-Young and Potschin, 2010)

De Groot et al. (2010) further developed above described framework from Haines-Young and Potschin (2010) by adding a component to illustrate the importance of valuing generated benefits. Value component highlights the fact that not all generated benefits are market based and valuing some of the benefits may require more advanced valuation methods. De Groot et al. (2010) argue that ecosystem services have a huge impact on the multiple aspects of human welfare, so it is only smart to measure the magnitude of the different welfare aspects by valuing the impacts. Comprehensive valuation of potential benefits provides a tool to evaluate trade-offs that occurs with different management strategies.

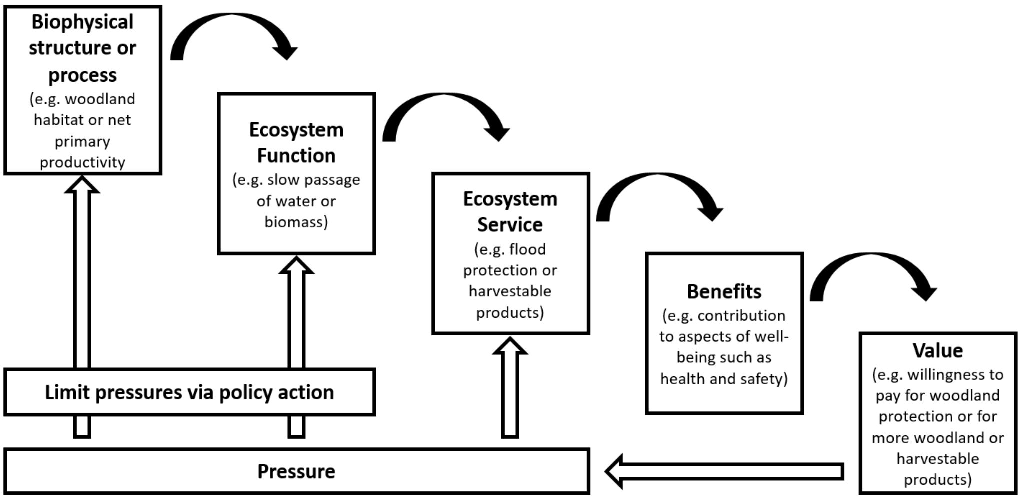

Figure 2: The ecosystem service cascade model initially proposed in Haines-Young and Potschin (2010) modified to separate benefits and values in de Groot et al. (2010)

Cascade model is a simple approach where cascade between two ends of a "production chain" is clearly displayed, which is a key advantage compared to MEA (Haines-Young and Potschin, 2010). Cascade model shows the path from ecological structures to an ecosystem benefit, and it illustrate how wide spectrum of different steps are needed before nature can provide ecosystem services. With cascade model the trade-offs between different functions are more easily recognized since the links are presented in more detail. De Groot et al. (2010) note that more detailed and more informative presentation would help decision makers to realize a complexity of ecosystem services. Double counting issue was related strongly to MEA, however, with cascade model the problem is considerably smaller and easier to avoid due to separation of ecosystem function and the ecosystem service. Böhnke-Henrichs et al.

(2013) state that those ecosystem service classification models, which include the supporting service category into typology are not recommended for using in economic valuation studies. (de Groot et al., 2010)

De Groot et al. (2010) in TEEB, developed typology of ecosystem services from the MEA approach. Typology of ecosystem service used in TEEB is listed in table 2. Typology used in TEEB is provided here as an example because it is widely adapted classification and many studies today are referring to it (e.g. Böhnke-Henrichs et al., 2013 & Hattam et al., 2015). Most fundamental changes in TEEB compared to MEA, were conducted in categorization, when supporting service was relocated to its own component and habitat service was included into the classification as a separate service type. TEEB identified habitat service as a separate service type in order to highlight the importance of ecosystem to provide nursery service for migratory species and maintain good habitat to protect gene pool. State of the habitat is defining factor in provision of these services. For example, many commercial fish species use mangrove ecosystems as nursery service for their pawn. This service has clearly economic value, but it is easily overlooked since fishes are caught elsewhere (Barbier, 2017). Habitat service ensure that nursery service is being valued properly.

Haines-Young and Potschin (2018) in Common International Classification of Ecosystem Services (CICES), formed ecosystem services typology, which differs slightly from de Groot et al. (2010). In general, the two typologies are almost identical but there is one service type less in CICES than TEEB. In TEEB, *regulation* and *habitat services* are two separate service types but in CICES those categories are compounded into one service type called *regulation and maintenance service.* Two other service types in CICES are the same as in TEEB: *provisioning service* and *cultural service*.

Table 2: Typology of ecosystem services in TEEB (de Groot et al., 2010)

	Service types
	PROVISIONING SERVICES
1	Food
2	Water
3	Raw Materials
4	Genetic Resources
5	Medicinal resources
6	Ornamental resources
	REGULATING SERVICES
7	Air quality regulation
8	Climate regulation
9	Moderation of extreme events
10	Regulation of water flows
11	Waste treatment
12	Erosion prevention
13	Maintenance of soil fertility
14	Pollination
15	Biological control
	HABITAT SERVICE
16	Maintenance of life cycles of migratory species
17	Maintenance of genetic diversity
	CULTURAL AND AMENITY SERVICE
18	Aesthetic information
19	Opportunities for recreation and tourism
20	Inspiration for culture, art and design
21	Spiritual experience
22	Information for cognitive development

It is controversial, whether abiotic components should be included into ecosystem service classifications. On the one hand, argument can be made that abiotic components are ecosystem services because they are integral to ecosystems and they are determining ecological functions. For instance, Atkins et al. (2011) and Lillebø et al. (2017) included abiotic raw materials and human activities like non-renewable energy generation and shipping into the classification. On the other hand, arguments can be made that abiotic components should not be included in the classification because ecosystem services are meant to be delivered by the living components of the ecosystem. The Common International Classification of Ecosystem Services (CICES) solved this problem by developing a separate classification for abiotic outputs from ecosystems. (Hattam et al., 2015)

Costanza et al. (2017) are not too fond of the cascade models and they state that it is far too simple approach to a complex reality. They declare that model should better highlight how complex, non-linear and dynamic is the relationship between ecosystem functions and ecosystem benefits. At the same time, Costanza et al. (2017) argue against a distinction of services and benefits. They are asking is there really a difference between benefits and services, when ecosystem services are, by the definition, functions and processes of ecosystems that benefit humans, directly or indirectly, whether humans perceive those benefits or not. Potschin and Haines-Young (2016) admit that cascade model describes the relationship between ecological structures and generated value as a rather linear way, and therefore the model is limited. However, regardless of simplicity, they argue that the model is standing on its ground because elements in cascade model provide tools for representing and understanding complexity of ecosystem services.

Potschin-Young et al. (2018) conducted a research of role of the cascade models in work of ecosystem services. They found out that multiple studies have used cascade models in past ten years. In those studies, cascade models have been used inter alia as an organising structure to help simplify a complex reality, to re-frame biodiversity-related issues and for providing analytical template for empirical research. Research revealed also some issues related to cascade models, since in few studies participants were not familiar with the classification structure of the model. For example, participants were confused by the concepts of ecological functions and ecosystem services, and many times distinction between services and benefits caused uncertainty for the participants and their stakeholders. Potschin-Young et al. (2018) assumed that problems were caused by poor guidance rather than some fundamental problem of the model.

2.2 Marine ecosystems goods and services

Marine ecosystem services include a wide range of habitats and ecosystems, since marine and coastal environments can be considered to begin from 100 kilometers inland (Barbier, 2017). Several ecosystem service classifications exist, as stated earlier, but most of them have been developed with a terrestrial focus, therefore they cannot be directly adapted to marine ecosystem services (Liquete et al., 2013). Still, there are some ecosystem service studies and classifications in the literature, which are targeted specifically for the coastal and marine habitat (e.g. Beaumont et al., 2008; Atkins et al., 2011; Böhnke-Henrichs et al., 2013; Liquete et al., 2013; Hattam et al., 2015; Lillebø et al., 2017).

Böhnke-Henrichs et al. (2013) notice that ecosystem service concept was rarely used for maritime planning because only few classification models had been made for the marine ecosystem services. Beaumont et al., (2008) and Atkins et al. (2011) were among firsts attempts to define classification model specific for marine ecosystem services. Unfortunately, those models were not suitable to analyze economic trade-offs properly because they took example from MEA (2005) by including category of supporting service within the typology. In addition, Böhnke-Henrichs et al. (2013) stated that Beaumont et al. (2008) fail to keep distinctions between services, benefits and values because they include ‘option value’ as a service type.

Böhnke-Henrichs et al. (2013) and Hattam et al. (2015) released separate classification models of marine ecosystem services, which were based on the TEEB typology. Böhnke-Henrichs et al. (2013) and Hattam et al. (2015) adapted the TEEB typology because the framework distinguishes between ecosystem processes, services, benefits and values. Frameworks from Böhnke-Henrichs et al. (2013) and Hattam et al. (2015) are different with each other only on minor details. For example, Hattam et al. (2015) did not include seawater as an ecosystem service and they separated wild captured and farmed seafood from each other. Otherwise, the two frameworks are identical. Framework from Böhnke-Henrichs et al. (2013) is presented in table 3.

Table 3: Typology of marine ecosystem services (Böhnke-Henrichs et al., 2013)

Theme	Ecosystem service	Description	Example
Provisioning Services	1. Sea Food	Marine fauna and flora provide food for humans	Seafood, seaweed
	2. Sea Water	Marine water in oceans, seas and inland seas, which are extracted for economic benefits of humans	Seawater used in shipping, industrial cooling
	3. Raw Materials	Coastal and marine environments provide materials for consumption	Non-food algae, sand, salt
	4. Genetic Resources	Marine flora and fauna provide genetic materials for use in non-marine and non-medicinal contexts	The use of marine flora and fauna-derived genetic material to improve crop resistance to saline conditions
	5. Medicinal Resources	Coastal and marine environments provide materials for medicinal benefits	Marine-derived pharmaceuticals
	6. Ornamental Resources	Coastal and marine environments provide materials for decoration, fashion, jewellery, souvenirs, etc.	Shells, aquarium fishes, pearls, coral
Regulating Services	7. Air Purification	Coastal and marine ecosystems provide air purification service	The removal from the air of pollutants like fine dust
	8. Climate Regulation	Biotic elements of a coastal and marine ecosystems provide maintenance of a favourable climate conditions	The production, consumption and use by marine organisms of gases
	9. Disturbance Prevention	Marine ecosystem structures mitigate the intensity of environmental hazards such as storm floods, tsunamis, and hurricanes	Marine ecosystem structures like salt marshes, sea grass beds, and mangroves, directly reduce environmental disturbance
	10. Regulation of Water Flows	Marine and coastal ecosystems maintain current structures of localized coastal currents	Macro algae influence localized current intensity
	11. Waste Treatment	Coastal and marine ecosystems are able to remove pollutants by processes such as storage, burial, and biochemical recycling	Shellfish filter and purify coastal waters
	12. Coastal Erosion Prevention	Coastal and marine ecosystems provide Coastal Erosion Prevention	The maintenance of coastal dunes by coastal vegetation
	13. Biological Control	Marine and coastal ecosystems maintain food web structure and natural healthy population dynamics	Herbivorous fishes minimize algae population for the benefits of reef ecosystems

Habitat Services	14. Lifecycle Maintenance	Particular marine and coastal habitats provide essential environments for migratory species' populations to reproduce and maturate juveniles.	Provide reproduction habitat to species that are harvested elsewhere
	15. Gene Pool Protection	Marine habitats maintain viable gene pool through natural selection and evolutionary processes	Marine ecosystems are supporting genetic diversity, which helps species to better adapt for changing environment
Cultural & Amenity Services	16. Recreation and Leisure	Particular state of marine and coastal ecosystems is needed for some recreation and leisure opportunities	Birdwatching, sailing, recreational fishing, scuba diving, etc.
	17. Aesthetic Information	Coastal and marine ecosystems contribute to the landscape which generates emotional reaction within the individual observer	The visual facets that emotionally resonate with individual observers.
	18. Inspiration for Culture, Art and Design	Coastal and marine ecosystems provide environmental features that inspire culture, art and design.	The seascape has inspired directors, painters and musicians in their work
	19. Spiritual Experience	Coastal and marine ecosystems may help to create religious experiences	Many ancient mythologies and religion have used the sea as part of their narratives
	20. Information for Cognitive Development	Coastal and marine ecosystems contribute to e.g. education and research	Marine ecosystems condition impacts environmental education for all age groups
	21. Cultural Heritage and Identity	Coastal and marine ecosystems have influence on Cultural Heritage and Identity. This includes the importance of marine and coastal environments in cultural traditions and folklore.	Seas are listed as UNESCO World Heritage sites for example the Wadden Sea.

3 Food from the ocean – aquaculture & wild capture

Marine ecosystem services provide fishing and aquaculture opportunities, which provides food, employment and income for millions of people all over the world. Nutritionally fish and fish products are huge part of the people's diet, especially in least development countries, where fish plays a major role in food security (Ye et al., 2013). In 2015, least developed countries' fish protein intake was approximately 26% of their all-animal protein intake, while people in developed countries received 11% of their diets' animal protein from fishes. Outliers in this data are the world's poorest countries, like Bangladesh, Cambodia and Ghana, where people receive more than 50% of their animal protein intake from the fish. Majority of world's population growth is happening in least development countries, where the fish consumption is already high. Hence, healthy fish stocks and aquaculture are in key role, when world's constantly growing population are tried to feed. (FAO, 2018)

3.1 World's aquaculture and wild capture

World's total marine food production was 171 million tonnes in 2016 and about 88% of that was directly utilized in human consumption. From the total seafood production, about 53% comes from wild capture and 47% from aquaculture. Intensive growth in last two decades of the aquaculture have been remarkable, since in 1990, aquaculture's share of the world total seafood supply was only around 10%. When considering the great increase, it seems clear that in near future aquaculture's contribution to fish and other seafood supply will exceed that of wild capture fisheries. (FAO, 2018)

Aquaculture has grown fast in past 20 years and in this point in time, it has important role in global food supply and economic growth (Scientific, Technical and Economic Committee for Fisheries, STECF, 2018b). FAO (2018) calculated that global value of aquaculture production was €220 billion in 2016, which is four time greater than the same value in 1990. Total aquaculture production was 80 million tonnes in 2016 and it was divided to inland and marine production, 64% and 36%, respectively. Aquaculture markets have formed naturally to Asia, since over 89% of the world's aquaculture products are produced there. China is the global market leader in aquaculture sector with 62% market share. (FAO, 2018)

Despite the growing attention that aquaculture production has received, still wild capture fisheries remains significant for overall supply of the seafood. World’s total marine catch have declined slightly from 81.2 million tonnes in 2015 to 79.3 million tonnes in 2016. Marine catches have stayed around the same level since 1995, and major reasons for that is the overfishing, pollution and habitat loss (Ye et al., 2013). Even though the wild capture fish yields have been stagnated for almost 20 years, stocks could grow and provide higher yield in the future if managed properly. (FAO, 2018)

In economic terms, the marine food production is highly relevant, since they are some of the world most traded food items. In 2016, 60 million tonnes of fish and fish products were exported with a value of USD 143 billion, trade have increased by 7% over the year before. Fishery provides livelihood to millions of people, since in 2016, 59.6 million people received their income from primary production of either fish capture or aquaculture, 32% were working in aquaculture and 68% in fisheries. (FAO, 2018)

3.2 Wild capture fish in the EU

In 2016, the EU fleet landing reached 4.9 million tonnes, which represent about 5-6% of the global landing. The value of total landing in EU was €7.7 billion and it was 9% more than year before. Overexploitation has been affecting negatively on a EU’s wild capture, since it lowers the harvesting opportunities and increases costs. Five member states (Spain, France, United Kingdom, Italy and Denmark) accounted over 70% of EU’s total landed value, Spain was the largest (25%) followed by France (15%). Same five countries accounted also a major part (60%) of the EU’s total landings by weight. In 2016, Atlantic herring, Atlantic mackerel and European sprat were the most landed species in terms of weight. Top species in terms of value were European hake, yellowfin tuna and Atlantic mackerel. (STECF, 2018a)

Fleet capacity of the EU fell by 1% from year before and accounted 83 360 vessels in 2016. Total number of vessels are divided into two groups: active and inactive. Active vessels accounted for 65 398 in 2016 and it has increased by 2% in a year, while number of inactive vessels declined by 12%. Total capacity of EU fleets has been declining for numerous of years and the same trend can also be seen in other developed countries (Ye and Gutierrez, 2017). Total amount of vessels in EU have declined 14% from 2008. Since 2008, fleet capacity in EU has declined also in terms of engine power and weight; these sectors have decreased 14% and 18%, respectively. (STECF, 2018a)

Most of the EU landings are generated from the Northeast Atlantic, Baltic and North seas (FAO fishing area 27) and Mediterranean and Black seas (FAO fishing area 37). EU's fishing fleets operates also much further away from the EU continent and these areas are called "other fishing regions". The North Sea & Eastern Arctic area accounts largest share (32%) of landing in terms of weight, followed by Northeast Atlantic (30%), other regions (15%) and Baltic Sea (13%). In terms of value, the Northeast Atlantic is the largest area by 33 percent, followed by North Sea and Eastern Arctic (27%), Mediterranean Sea (18%) and other regions (16%). (STECF, 2018a)

3.3 Aquaculture in the EU

In world scale, the aquaculture is approaching already total production of wild capture fish, but the case is not the same in EU, where aquaculture production covers only about one fifth of the whole seafood production. European Union's aquaculture production was 1.42 million tonnes in 2016, which was only 1.6% of world aquaculture production. Value of the production reached €4.89 billion in 2016, covering 2.2% of world's total aquaculture value. EU's aquaculture production is divided into three subsectors: marine fish, freshwater fish and shellfish. In terms of volume, European Union's most produced subsector is shellfish (e.g. mussels and oysters), but in terms of the value, the biggest subsector is marine cultured fish. In 2016, shellfish production covered 47% of the Europe's total production weight, marine fish 31% and fresh water fish 22%. Marine fish provides 55% of European aquaculture value, shellfish 23% and freshwater fish 21%. Prominent growth rates that has been observed in aquaculture production in all over the world, unfortunately, have not boosted European production, since total aquaculture production in Europe has stayed virtually unchanged for over 15 years. Even though the total production has not increased, the value of the production has grown significantly. (STECF, 2018b)

Even though, the growth rate of the aquaculture has not been significant, still EU acknowledge the importance of the aquaculture sector for achieving future’s food safety. EU has tried to generate growth by investing €1.17 billion to aquaculture sector over the period 2000-2014 and €1.72 billion over the period 2014-2020 (Guillen et al., 2019). In European Commission’s strategic guidelines for the sustainable development of EU aquaculture (European Commission, 2013b), four priority areas were identified, that should be taken into account in order to improve overall performance of the aquaculture industry. For boosting aquaculture, European Commission advices that: administrative burden should be reduced, access to space and water should be eased, actions should be taken to improve aquacultures competitiveness, and competitive advantages should be searched from the health and the environmental aspects. European Commission’s Blue Growth Strategy also lists aquaculture as a sector that have high potential to provide sustainable jobs and growth in a future (European Commission, 2017). Desire to grow aquaculture sector does not come unilaterally from European Commission because member states expressed their willingness to participate in the challenge by stating in the Multiannual National Strategic Plan for the development of aquaculture activities that by 2020 EU marine finfish aquaculture production should be increased 60% and the shellfish production by 25% (European Commission, 2016).

EU’s aquaculture is highly concentrated since five countries (Spain, France, United Kingdom, Italy and Greece) are covering 74% of the total production volume. The biggest producer in volume is Spain with 21% market share but United Kingdom has largest production value. This is explained with low market price of mussels, which represented 74% of the Spanish aquaculture production volume. European Union cultured fishes are mostly centralized between three species: Atlantic salmon, gilthead seabream and European seabass. Those three species cover 86% of EU’s total sales volume and total sales value. EU’s main farmed shellfish species in 2016 were Mediterranean mussels, blue mussels, pacific cupped oyster and Japanese carpet shell. More than one third of the total value generates from Pacific cupped oyster (38%), smaller part of the value comes from blue mussels (22%), unidentified mussels (13%), Japanese carpet shell (11%) and Mediterranean mussels (8%). (STECF, 2018b)

3.4 Declining fish stocks

Global fish stocks have depleted significantly due to overexploitation, illegal, unreported and unregulated (IUU) fishing, pollution and habitat loss during the last decade, and addition to those, climate change and costal environmental damages are causing major uncertainties to fish stocks development (Ye et al., 2013). MSY is the largest average catch that can be harvested over time from a fish stock under specific environmental conditions without damaging its long-term renewability (Smith, 1980). Fish stocks are seen to be overexploited when abundance is lower than the level of MSY and underexploited when abundance is above MSY. According to FAO (2018), the percentage of fish stocks fished at biologically unsustainable[1] level was 33% in 2015 and it has increased 23% on the last 40 years. Situation is extremely alarming with commercially fished stocks, where around 80 percent of the stocks are either overexploited, significantly depleted or fully exploited (Barkin and DeSombre, 2013). World’s fish harvest was at its highest point around 1998 and after that the harvests have been fallen year by year. After 1998, overfished stocks have increased nearly 10% and fishing industry has shifted to exploit formerly less harvested stocks (FAO, 2018).

According to FAO report ´the State of World Fisheries and Aquaculture 2018´, Mediterranean and Black Sea, Pacific-Southeast and Atlantic-Southwest are the most overexploited marine areas of the world, with overfishing rates about 40%. Report reveals that the situation is particularly challenging in the Mediterranean and Black

[1] Stock less abundant than the level needed to produce MSY (FAO, 2018)

Sea, where the total landings have decreased considerably; the total landings was 2 million tonnes in the mid-1980s but due to overfishing, the landings were only 1.1 million tonnes in 2014.

Even though the problem of overfishing has been acknowledged by different stakeholders for several decades, it still remains unresolved, and unsustainable fishing continues. In all its simplicity, fish stocks are dwindling because too many vessels are trying to make their living by chasing unsustainably managed stocks. In other words, biggest reason for declining fish stocks is a combination of overfishing and overcapacity and these are mainly consequences of the open-access character of the marine fishery resource. Luckily, fish stocks are reversible, and stocks should return to sustainable state after adequate recovery period but only if global fishing effort is reduced. Solution is that simple in theory, but in reality, it requires fishers to accept temporarily reduced income to revive stocks and, in many cases, it is too much to ask because many fishers are dependent on food and income that marine resources provide. (Clark, 2007)

Marine renewable resources are open for everyone, since marine property rights cannot be clearly defined. Everyone can fish with appropriate equipment and that creates fierce competition of this common resource. Individual fisher is maximizing its profits by maximizing catch and in competitive situation, individual fisher has incentive to fish as much as possible, as fast as possible. Gordon (1954) showed that in unregulated open-access fishery, competition for scarce resource continues until the point is reached, where total revenue equals total costs, thus the profit equals zero. Equilibrium is reached in the zero-profit point because gained economic surplus from open-access fishery attracts excessive level of effort into the fishery and competition between fishing fleets continues until rising harvesting costs are meeting declining revenues, due to an overexploitation of the stock. In open-access long-run equilibrium, fish stock is biologically overfished because the catches exceed MSY. Clark (1976) developed Gordon’s theory by stating that fishers will harvest the stock to a point, where growth rate of the stock equals discount rate of the market. After this point, it is optimal to abandon the resource and invest the money to somewhere else, since the markets provide higher interest rate. Results from Gordon (1954) and

Clark (1976) clearly state that without any regulations, fish stocks are in danger to be overexploited due to open-access.

Positive rents from the well-managed stocks attracts new fleets into the market and this trend have led to overcapacity of the global fishing effort, which is major impediment to achieve sustainably managed fish stocks (Beddington et al., 2007). Wakening to the fact that overcapacity is extremely harmful for the stock development, has led to attempts to reduce global fishing effort. Developed countries have reduced their effort from 1990s by a half and downward trend is still going on, but in global scale, the effort is still growing because developing countries have nearly tripled their effort compared to 1990s level. Rapid decrease in developed countries was achieved by tightened regulations, management interventions and relocations of fishing fleets. (Ye and Gutierrez, 2017)

IUU fishing is a global phenomenon and it threatens the sustainability of fish stocks. Illegal fishing refers to actions, where fishers operate in the exclusive economic zones (EEZ) or in international waters despite laws and regulations. Unreported fishing occurs when fisher does not report harvested amount correctly and harvest exceeds individual quotas. Fishing is unregulated when it is taken place in areas or of fish stocks, where there are no conservation or management measures. IUU fishing hampers the rebuilding process of the fishery and reduces harvesting opportunities for legal fishers. Fishery regulations and fish stock management are in danger to become ineffective because of the IUU fishing. (Hutniczak et al., 2019)

Awareness is raising from IUU fishing and work has already been done to eradicate it. For example, the United Nations states in Sustainable Development Goals (target 14.4) that *"By 2020, effectively regulate harvesting and end overfishing, illegal, unreported and unregulated fishing…in order to restore fish stocks in the shortest time feasible, at least to levels that can produce maximum sustainable yield as determined by their biological characteristics"*.

Attempts have been made to quantify the IUU fishing problem. Agnew et al. (2009) studied IUU fishing in 54 countries and they estimate its annual value to be between $10 and $23.5 billion. Their data indicates the situation to be worst in developing countries, for example in West Africa the catches were 40% higher than originally was reported. Pramod et al. (2019) tried to assess how big part of the Japan's imported seafood is coming from the illegal and unreported sources. They found out that 24-36% from the total import amount (2.15 million tonnes) was from IUU sources, with the estimated value of $1.6 to $2.4 billion. Pramod et al. (2014) reported similar results when they stated that 20-32% of the wild-caught seafood imported to USA was from IUU sources in 2011, with the estimated value between $1.3 and $2.1 billion.

3.5 Fishery management

Different management tools are used in order to achieve sustainable stock level. Traditionally the management tools for fisheries are divided into two groups depending on whether it affects catch (output) or fishing effort (input). Output control managements prescribes what and how much is allowed to be harvested and input control defines how, when and where to harvest. Output control includes total allowable catches (TAC), quotas, trip limits and size limitations, when input control includes closed seasons, fishing rights, protected areas and technological control on fishing vessels and gears (Morison, 2004). Indirect management tools, such as fees and subsidies, have been used alongside with output and input control. Indirect management tools aim to affect the cost structure of fishing and by that, setting the fishing effort to more desirable level. (Flaaten, 2011)

Most of the EU's commercial fish stocks are managed by fishing quotas (European Union, 2013). In fishing quotas, total allowable catch (TAC) is defined for each stock and total catch is set low enough to allow population to recover. After this, the TAC is often divided to each fishing unit and each fishing unit is not allowed to fish more than their share of the TAC. Individual fishing quotas can be transferable and sellable, thus owners of the fishing units face an optimization problem, whether to sell their quotas or use them for themselves. Under the fishing quotas, fishers no longer compete catches with each other since they are guaranteed to receive a certain proportion of the catch, which allows them to make rational economic decisions of their fishing strategy (Beddington et al., 2007). Ideally, fishers who do not have proper economic conditions to fish, will sell their quotas and the ones who remains, are fishing economically optimal manner. (Clark, 2007)

Fishing quotas have also received some critique. It is obvious that there is incentive to catch more than quota allows and adequate enforce must be in place to prevent illegal fishing. Although, the peer pressure might prevent some of the biggest misuse of the quota, since overexploitation by one fisher is harmful for all. Fishers have also economic incentive to fill their quota only with most valuable fishes and therefore discard all small-sized and undervalued fishes. Excessive discard may result to a higher fishing mortality than originally was planned, and in some cases, these discarded by-catches can be largely overexploited. Fairness of quota allocation has also been questioned since quotas are valuable assets and it is hard to justify, why the common resource is divided only with a selected group. (Clark, 2007)

Ye et al. (2013) state that only solution for achieving sustainable catch level, is to limit fishing activity of the fleets. One already used solution is the buy-back programs, where the vessels are bought from the fishers and eventually scrapped. Objective of the program is to lower exploitation pressure by reducing vessel number, which lead to stock recovery and increasing resource rent. In order buy-back programs to work, licences and vessels must be registered properly, and market access must be regulated, otherwise new vessels would replace vessels that were pulled of the market and total number of vessels would remain unchanged. Likewise, to ensure efficiency of the program, licences should be bought along with the vessels, otherwise licences will be sold to other vessel and the total catch would remain untouched (FAO, 2006). However, Clark (2007) argued that buy-back program would fall short from its objective because fishermen are willing to sell only the least effective vessels, leaving total fishing capacity largely intact. Secondly, the buy-back programs do not change the economic incentives which originally led to overcapacity, and for that reason, fishing effort will most likely increase after the buy-backs (Clark, 2007).

At some cases, the best management alternative is to affect the profit function of fishing, by either increasing costs or decreasing revenue. Regulator can use Pigouvian taxes for either effort or harvest control, to adjust the fishing effort to the optimal level. In order to find the tax rate, which leads to optimal effort level, regulator needs an extensive knowledge of biological and economic characteristics of the fishery. Obviously, it is hard to collect accurate data since fishers are not usually willing to reveal their numbers, and the parameter estimation process is not free of uncertainties. However, every tax rate, also those that are lower than the optimum, will move the equilibrium to the sustainable direction, even though the optimum level might not be reached. (Clark, 2007)

A lot has been written about landing fees and quota controls. Particularly interesting research subject has been to examine, under which circumstances regulator should select quotas over fees, and vice versa. According to Hansen and Jensen (2017), fees are more suitable alternative than quotas if ecological uncertainty dominates or if there is uncertainty in variable economic, such as in fish prices. However, quotas should be selected over fees if there is uncertainty in structural economic, for example in profit function parameters.

Much discussed topic in today's fishery politics is the removal of the harmful subsidies. Subsidies for profit improvement, by either lowering fishing costs or increasing revenue, are impairing the sustainability of fisheries because they lead to a bioeconomic equilibrium with a higher level of fishing effort and lower stock size (Beddington et al., 2007; Clark, 2007). The issue is significant enough that United Nations Conference on Trade and Development (UNCTAD) and FAO published joint report (UNCTAD-FAO, 2016) where they are giving their total support to international efforts to achieve a Sustainable Development Goal 14, which is exclusively dedicated to the conservation and sustainable use of oceans, seas and marine resources. This SDG-14 includes specific target to prohibit those fishing subsidies that leads to overcapacity and overfishing (SDG-14.6). The joint report has been a focal dossier and good starting point for WTO discussions towards regulating fishing subsidies and it is already endorsed by 90 countries (FAO, 2018).

3.6 Rebuilding fishery

Many fish stock is exploited at rates that are not capable of delivering the MSY and thus, world's fishing industry is losing potential economic benefits. Several studies have highlighted the fact that potential profits of global fisheries could be considerably higher if stocks were exploited sustainably (Willman et al., 2009; Srinivasan et al., 2010; Crilly and Esteban, 2012; Sumaila et al., 2012; Ye et al., 2013; Costello et al., 2016; Guillen et al., 2016; Hilborn and Costello, 2018). Hilborn and Costello (2018) estimated that global fisheries yields could potentially increase by about 13-17% from 2012 levels, with better management strategy. They identified from where (fishing underutilized stocks more intensively or rebuilding overexploited stocks) the potential increase in yield could come on different part of the world. Interestingly, those areas that manage their fisheries intensively such as Europe and North-East Pacific could increase their yield mostly by exploiting underutilized stocks more comprehensively. Costello et al. (2016) calculated that global catch would increase from 80 million tonnes to 98 million tonnes if all stocks would be managed as MSY. Guillen et al. (2016) used surplus production model to estimate the potential profit for the EU fleet operating in the Northeast Atlantic waters and according to their results, effort needs to be reduced 38% to achieve healthy and profitable state of the stocks. They estimate that operating profit of EU fleet would increase from €0.1 billion to €4.64 billion if biomass of all stocks could recover and harvest would follow MSY. Operating profit would rise to €4.91 billion if fisheries were managed at MEY.

Crilly and Esteban’s (2012) results were in line with previous studies, when they stated that fishers would gain potentially higher economic rents if Northeast Atlantic stocks would be restored to MSY. However, their work was different from others in a sense that they paid attention to social costs that occurs when fish stocks are rebuild. They estimate that €10.56 billion is lost in transition period (9.4 years) due to lower fishing effort. This economic loss can be seen as an investment for rebuilding the global fish stock. The investment is profitable already in transition period, since return on investment in that period is 148%. The return on investment is even higher after 40 years of rebuilt, for every Euro invested, 14 is returned. Crilly and Esteban (2012) suggest that the fastest way to move forward is to engage private sector into process and they believe that the return of investment is already in an adequate level to attract private investors. Willman et al. (2009) also noted that investments are required in order to guarantee smooth and fair transition to economically healthy fish stocks. Public funds have been often used to support fishers for abandoning the profession (e.g. buyback programs and early retirement packages) but public money can achieve only limited results and therefore private investments are desperately needed.

4 Methods and objectives

Objective of this study is to estimate the value of the European Union's potential fish landing in the Northeast Atlantic. Fish stocks are right now managed in too short-sightedly, and because of that, EU is unable to take full advantage of the true potential of the stocks. It is well known, that healthier fish stocks combined to sustainable harvest levels could provide more landings and increase profits in long term. Aim of this study is to define how much additional economic benefits would be provided if the Northeast Atlantic stocks would be managed sustainably.

EU fleets are currently operating inefficiently in terms of both catch and profit, and the growth potential of EU's wild capture production in Northeast Atlantic were calculated. Study compares current production and theoretically maximal production, which is determined by assuming that all fish stocks could provide Maximum Sustainable Yield (MSY) at the same time and effort level of the fleet is reduced to a level where catching MSY is possible. Study compares different rebuilding pathways to achieve collective MSY by calculating rebuilding time and net present value for each pathway. This study also views seafood production as a whole and provides rough estimation of combined production of aquaculture and wild capture in Northeast Atlantic.

The study takes an example of paper published by Guillen et al. (2016) and objective is to follow their study in order to see at which direction have the Northeast Atlantic fish stocks developed and have the EU's position changed in relation to MSY. To ensure comparable results, method of this study follows the method of Guillen et al. (2016). They used regular Gordon-Schaefer bioeconomic model to interpret the fisheries growth in equilibrium and outside of the equilibrium, they adapted formulas from Pella, (1967) Schnute, (1977) and Prager (1994). Guillen et al. (2016) used European Total Allowable Catch (TAC) landings and data of different species' MSYs to form aggregated production curve of Northeast Atlantic fisheries. European potential fish landings value in Northeast Atlantic were determined from aggregated curve.

4.1 Gordon-Schaefer bioeconomic model

Ecosystem services that benefit the people are restricted by the health of the natural capital. Profit and landing gained from fishery is dependent on the state of the stock. In this study, the Gordon-Schaefer model is used to determine state of the natural capital at each input level.

The Gordon-Schaefer model is a bioeconomic model proposed by Schaefer (1954) and Gordon (1954) and it has become the standard framework of fisheries economics. The model is used for determining sustainable stock size and optimal harvesting effort to maximize long-term benefits of the resource.

The model is presented here in three steps. First, the model is provided only from biological point of view, excluding all the prices and costs. Second, the economic part is added into the model and the stock is fished economically optimally, so fishers are maximising their common long-term profits of the stock. In third step, the economic part still exists in the model but now the stocks are assumed to be open-access, where everyone can enter the market and every vessel is maximizing only its own profit.

4.1.1 Biological optimum

Biological growth function is the basic structure of the model and it is formed as:

$$F(x) = rx\left(1 - \frac{x}{K}\right) \qquad 3$$

where F(x) is the natural growth rate of the fish population, x is biomass, r is the intrinsic rate of natural population growth and K is the environmental carrying capacity for the population. Parameter r varies according to different species while K depends on natural characteristics of the habitat, both parameters are assumed to be fixed. Natural growth is acting according to equation (3), and it can be seen from the equation, that natural growth of a stock is positive until it exceeds the level of K. When x > K, the negative term inside the brackets is dominating and shifts growth to the downward trend.

Natural growth reaches its maximum in a specific stock level, which can be obtained by maximising F(x) with respect to x. Stock level, which maximize natural growth, produces the maximum sustainable yield (MSY) and it can be found in a point where growth functions derivative is zero. When there is no harvesting, natural growth is maximised with stock size x_{msy}, which is formed as follows:

$$x_{msy} = \frac{K}{2} \qquad 4$$

The maximum growth can be further calculated by combining equations (3) and (4), which gives:

$$F(x_{msy}) = \frac{rK}{4} \qquad 5$$

According to equation (5), the maximum sustainable growth for any given stock is a quarter of the multiplication of parameters r and K.

The Gordon-Schaefer model does not only look at a natural growth but also adds the harvesting decision into equation. The model assumes that harvest will depend on the fishing effort, stock size and the catchability coefficient, as follows:

$$h = qEx \qquad 6$$

where h denotes harvest, q is the catchability coefficient, E is the fishing effort and x is stock size. The fishing effort describes how much resources have been allocated to fishing, for example number of vessels, efficiency of vessels and how many days those vessels have been out a sea (Perman et al., 2003). Different effectivity and technology of the fishing equipment are taken into account by the catchability coefficient. For example, trawlers will receive higher catch than boats equipped only with fishing rods and the catchability coefficient reflects this by giving higher value to more effective fishing gears. This study assumes that major technical improvements are not in sight, thus the catchability coefficient is assumed to be constant. Fishing effort is a decision variable and it can be changed based on fishers' decisions.

Stock change per unit as a function of time, can be defined by combining equations (3) and (6):

$$\frac{dX}{dt} = F(X) - h \qquad 7$$

where $\frac{dX}{dt}$ is the temporal change in x, $F(X)$ is natural growth and h is catch. Interrelation of the $F(X)$ and h determines the growth of the stock. Stock increases when $F(X) > h$ and decreases when $F(X) < h$. Stock achieve its biological equilibrium or steady state, when harvesting equals the net natural growth, $F(X) = h$. In this state, the harvesting can continue forever without causing any harm for a long-term steady state of the stock. Fish stock use is at sustainable state, when only the annual growth is harvested from the stock. Sustainable stock size and harvest level can be determined by using condition $F(X) = h$. By replacing the functions of $F(X)$ and h with equations (3) and (6), the function takes form of:

$$rx\left(1 - \frac{x}{K}\right) = qEx \qquad 8$$

Sustainable stock level (x_{msy}) can be determined from equation (8):

$$x_{msy} = K\left(1 - \frac{qE}{r}\right) \qquad 9$$

Equation (9) shows that sustainable stock size decreases when fishing effort increases. Sustainable harvest can be calculated by placing x_{msy} from equation (9) to equation (6). Thus, the sustainable harvest level is derived as:

$$h_{sustainable} = qEK\left(1 - \frac{qE}{r}\right) \qquad 10$$

The fishing effort that provides maximum sustainable harvest can be defined from equation (10). Fishing effort that maximise harvest is solved from derivation of equation (10) with respect to E. Thus, the optimal fishing effort is:

$$E^{msy} = \frac{r}{2q} \qquad 11$$

By placing E^{msy} to the equation (10), sustainable harvest is redefined as:

$$h^{msy} = \frac{rK}{4} \qquad 12$$

4.1.2 Economic optimal harvest

In this following chapter, the economic point of view is added to the model. Biological structure of the model is important to acknowledge but it is somehow theoretical and therefore economic parameters improve its usability. With prices and costs, the model can be used to describe real decision-making processes of fishers. The economic optimal harvesting model is based on three assumptions. First, the model assumes that fish price (p) is constant and fishers take the price as given, for example market price. The model also assumes that marginal cost of effort is constant, which is based on assumption that every vessel is added to the fishery at the same cost. Thirdly, the model assume that fish stock is owned by sole owner, for example State or EU, which controls the fishery in a way that economic benefits are maximised.

Objective of the biological model was to maximise the size of the fish stock, while economic optimal harvest model is looking to find management strategy to maximise economic profits of the fish stock. Definition of optimal economic harvest starts from the resource rent maximisation problem:

$$max(\pi) = ph - cE \qquad 13$$

where p is a fish price and c is a marginal cost. Equation (13) is a fisher profit function where the first term is the gross revenue of a fishery and the second term is the total cost of harvest. Economic optimal fishing effort can be estimated from equation (13) by combining it with equation (10) and then differentiating it with a respect of E. Fishing effort that maximise economic yield (E^{mey}) is then formed as:

$$E^{mey} = \frac{r}{2q}\left(1 - \frac{c}{pqK}\right) \qquad 14$$

Economically optimal fish stock size (x^{mey}) can then be estimated by combining equations (14) and (9), and it forms as:

$$x^{mey} = \frac{K}{2} + \frac{c}{2pq} \qquad 15$$

Economically optimal harvesting (h^{mey}) can be estimated by placing equations (15) and (14) to equation (6). When stock is fished economically, the optimal harvest is:

$$h^{mey} = \frac{rK}{4} - \frac{c^2 r}{4pq^2 K} \qquad 16$$

4.1.3 The open-access fishery

The open-access fishery occurs because property rights are undefined and access to resource is open and free for all. In open-access, fishers maximise their individual short-term benefits, which leads to overexploitation of the stock. Gordon (1954) showed that in unregulated open-access fishery, competition for scarce resource continues until the point is reached, where total revenue equals total costs, thus the profit equals zero. Taking advantage of Gordon's result, open-access fishery profit function is defined as:

$$\pi = ph - cE = 0 \qquad 17$$

The equation of fishing effort in open-access (E^{OA}) is formed the same way than in economic optimal harvest scenario. Equation (17) is combined with equation (10), from which the economic optimal fishing effort can be calculated. The open-access fishing effort is then:

$$E^{OA} = \frac{r}{q}\left(1 - \frac{c}{pqK}\right) \qquad 18$$

Open-access equilibrium stock size (x^{OA}) is defined by combining equations (9) and (18), it is formed as follows:

$$x^{OA} = \frac{c}{pq} \qquad 19$$

Equilibrium harvest size (h^{OA}) can be calculated by combining equations (6), (19) and (18). Harvest in open-access is:

$$h^{OA} = \frac{rc}{pq}\left(1 - \frac{c}{qK}\right) \qquad 20$$

4.1.4 Summary of the Gordon-Schaefer model

Unregulated open-access fishery will attract new vessels until opportunity cost[2] is lower than profit from the fishery. This can be seen from the figure 3, where revenue of the yield is presented on a function of effort. In figure 3, fishing effort increases (new vessels enter the market) until fishing costs equals the revenue of the yield. Thus, the open-access equilibrium point of effort is settled to E_{OA} because after this point every extra effort will turn into negative profits. From the society point of view, it would be more favourable to lower the effort level, because it would provide higher economic rent for fishers with healthier fish stocks. Moving from E_{OA} to E_{MSY} or E_{MEY}, provides more catch, more profits and healthier stocks with less effort. In figure 3, profit is presented with the space that is left between cost line and yield curve and it is maximised in effort level E_{MEY}. Total catch in MEY is lower than in MSY but profits are higher because costs decrease more than yield when moving from E_{MSY} to E_{MEY}. In MEY, total biomass size is greatest due to lowest effort level.

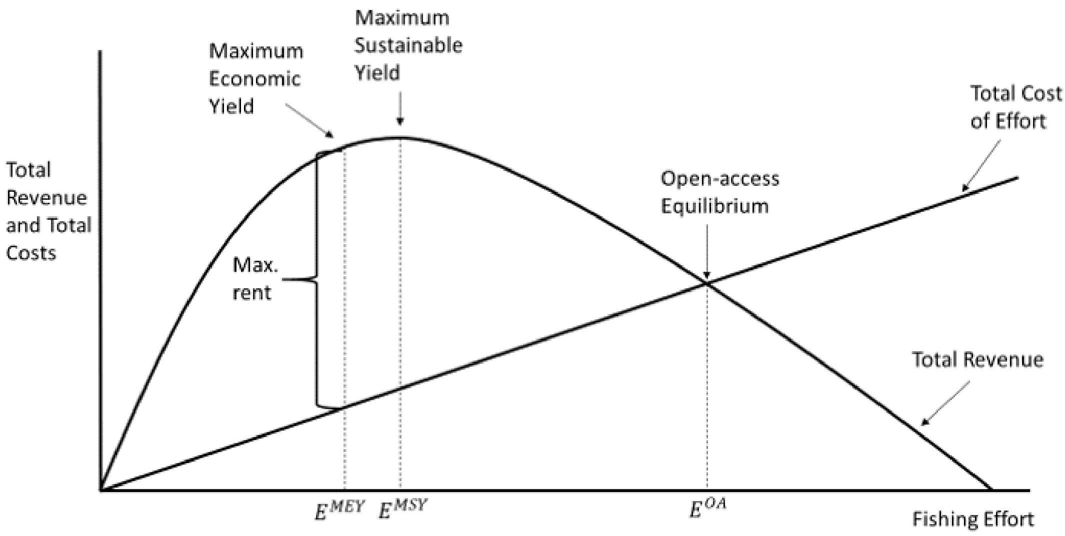

Figure 3: Summary of the different management options. (adapted from Sumaila, 2001)

[2] Profits that can be earned elsewhere in the economy.

The exact same results that were interpreted in figure 3 can be presented in algebra form by looking at the earlier presented equations. All equations that are needed to calculate the optimum levels in different management scenarios are represented in table 4. Comparing is intuitive between MSY and MEY, and by looking at the equations, it is clear that MEY leads to higher stock size with lower harvest and effort levels. It is not as straightforward to notice differences between open-access and MSY or MEY equations. However, numerical example would show that equilibrium point in open-access fishery is reached with higher effort and harvest levels and lower stock size. As a result, profits are notably lower in open-access than in MSY or MEY, thus, the world fish sector is not operating efficiently since potential economic rent is constantly lost because of too excessive fishing effort. Equations 21-24 gathers up and illustrate the comparisons between different variables in all three management scenarios.

Table 4: Summary of the equations of Gordon-Schaefer model.

	Open-access	MSY	MEY
Harvest (h):	$\frac{rc}{pq} - \frac{c^2 r}{pq^2 K}$	$\frac{rK}{4}$	$\frac{rK}{4} - \frac{c^2 r}{4pq^2 K}$
Stock size (x):	$\frac{c}{pq}$	$\frac{K}{2}$	$\frac{K}{2} + \frac{c}{2pq}$
Effort (E):	$\frac{r}{q} - \frac{cr}{pq^2 K}$	$\frac{r}{2q}$	$\frac{r}{2q} - \frac{cr}{2pq^2 K}$

$$E^{OA} > E^{MSY} > E^{MEY} \quad (21)$$

$$h^{MSY} > h^{MEY} > h^{OA} \quad (22)$$

$$x^{MEY} > x^{MSY} > x^{OA} \quad (23)$$

$$Profit^{MEY} > Profit^{MSY} > Profit^{OA} \quad (24)$$

4.2 Analysis outside of the equilibrium

The Gordon-Schaefer model works only when analysis is moving along the equilibrium curve. However, fish stocks are usually somewhere else than on an equilibrium curve, especially when stocks are tried to rebuild. MSY equilibrium point represent maximum sustainable harvest but it requires time before the fish stock is revived to a state where the MSY can be collected. In steady state, the system is in equilibrium, so at the certain harvest level the biomass of the stock remains constant because harvest equals annual growth. In order to rebuild the stock, the effort must be kept under the current equilibrium level, otherwise growth does not occur. The Gordon-Schaefer model defines variables in different equilibrium points, but it does not illustrate how long it will take to rebuild the stock and which is the optimal pathway to get there.

Pella (1967), Schnute (1977) and Prager (1994) have developed the equation of the dynamics in situation where harvesting effort does not match the equilibrium level ($\frac{dx}{dt} \neq 0$). From those three studies, Guillen et al. (2016) have formed aggregated equations to model rebuilding process of the fish stocks. It is formed as follow:

$$h_t = qE_tK\frac{\ln \alpha_t}{r} \quad 25$$

$$\text{being } \alpha_t = \left[1 - \frac{rx_t(1-e^{r-qE_t})}{K(r-qE_t)}\right] \quad 26$$

h_t is the harvest and E_t is the effort level, with both respect to time t. x_t stands for the biomass at the beginning of the period t. h_t gives a growth curve which is asymptotic at x_t. Because of that, the mean biomass $\bar{x}$ in period t is:

$$\overline{x_t} = K\frac{\ln \alpha_t}{r} \quad 27$$

Equation (25) can also be formed as follows:

$$h_t = qE_t\overline{x_t} \quad 28$$

To calculate the rebuilding time, the biomass at the end of the period t is calculated as:

$$x_{t+1} = x_t \frac{e^{r-qE_t}}{\alpha_t} \tag{29}$$

4.3 Profit function of the model

Operating profit is calculated by the difference between value of landing and total cost, as equation (30) show:

$$Profit = VL - TC \tag{30}$$

where VL is the value of landing and TC stands for total costs. In this study, the total costs of harvesting (TC) are assumed to be a linear function of the effort. In the other words, the marginal cost of effort is assumed constant. This cost method is simplified approach and it assumes that every vessel's cost structure is identical, which means that vessel is added to the fishery at the same cost than every other vessel. The total harvesting costs depends on the effort level as follows:

$$TC = cE \tag{31}$$

where c is the costs per unit of harvesting effort. The effort cost of harvesting (c) is obtained by summing all current cost components of the EU's Northeast Atlantic fleet and dividing it with a current effort level. Cost components that were taken account are cost of the crew wage (crew), estimates of unpaid labour (unpaid), energy cost (energy), other variable cost (other-variable), other non-variable cost (other-non-variable), depreciation (depreciation) and repair and maintenance (repair&maintenance).

$$c = \frac{\text{crew} + \text{unpaid} + \text{energy} + \text{othervar} + \text{othernonvar}}{+\text{depreciation} + \text{repair}maintenance} \tag{32}$$

Revenues that fishing provides is calculated by multiplying total harvest with fish price. Thus, the value of landing is defined as:

$$VL = ph \tag{33}$$

where p is price of fish and h is the amount of harvest. The price of the fish is the average price of the fish, which is calculated by dividing the Northeast Atlantic's total landing value with the total landing weight.

4.4 Forming collective MSY of the Northeast Atlantic stocks

Objective of the study is to estimate how much extra profits could be achieved if Northeast Atlantic fish stocks could be in state, where all of them can deliver MSY. The extra profit is estimated by the difference between current operating profit and operating profit in situation where all fish stocks are at MSY. Estimated MSY levels are taken from the literature (Merino et al., 2014; ICES, 2013; Guillen et al, 2013), unfortunately estimates are only available for a scarce number of species (S) and areas (Z). Guillen et al. (2016) have developed equation, which estimates potential landing value when MSY of all stocks could not be determined. In the equation, those stocks that have required information available ($MSY_{S,Z}$) are multiplied with the price of the species and summed together. In order to determine the potential landing value, the summed factor is then multiplied by a ratio of total EU landings value and EU TAC landings value. The idea is to estimate all of the Northeast Atlantic fish stocks MSY by assuming that the unknown fish stocks are behaving relatively same way as the stocks where MSY is known. The approach simplifies the complex problem but gives relatively good estimate of the Northeast Atlantic fish stock's MSY. Thus, the potential landing value is estimated as:

$$Potential\ landing\ value = \sum\left(MSY_{S,Z} * \ P_{TAC_{S,Z}}\right) * \frac{Total\ EU\ landings\ value}{Value\ of\ EU\ TAC\ landings} \qquad 34$$

where $MSY_{S,Z}$ is MSY for the species S in region Z and $P_{TAC_{S,Z}}$ is the price of the species S in region Z. Potential landing value corresponds the MSY of all the fish stocks in Northeast Atlantic.

The logistic production function (equation 10) gives harvest level (h) in a function of effort (E). Production function is fully defined when three of its points are known. First known point is the current value of landing and the effort level in Northeast Atlantic, which are obtained from the STECFs Annual Economic Report on the EU

Fishing Fleet (STECF, 2018a). Second known point is origin (0,0) since harvest is zero with zero effort. Third and final known point is the calculated potential landing value, which is the maximum point of the curve. With these three points, the curve can be defined and illustrated, since it is downward opening quadratic equation.

The logistic production function curve combines all Northeast Atlantic fish stocks, and parameters (r, K, q and x_{msy}) which are modelling the behaviour of aggregated Northeast Atlantic fish stock, can be defined from the curve. Intrinsic rate of natural population growth (r), the environmental carrying capacity (K), the catchability coefficient (q) and sustainable stock level (x_{msy}) can be calculated based on the curve. These parameters are further used to determine the changes in whole Northeast Atlantic fish stocks. Equations to calculate the parameters is presented in Annex 1.

4.5 Management points and alternative pathways to rebuild stocks

With method described above, four different management points were identified. Revenues, costs, efforts and profits of different management points were calculated. Different management points were then compared with each other in order to observe the differences between the points. Analysed four points are:

1) Point where MEY is collected (MEY)
2) Point where MSY is collected (MSY)
3) Point where EU fleet are currently (Current)
4) Open-access equilibrium point (Open-Access)

Second part of the analysis search for optimal rebuilding strategy to reach MSY for the Northeast Atlantic fish stocks. Eight different management scenarios were created for rebuilding the Northeast Atlantic's stocks and different options were compared by calculating rebuilding time and net present value. Used time perspective were 2019-2050. This study looks to rebuild the stocks to level where MSY is produced, and optimal effort level is the one which match the effort level of MSY. Defined management scenarios were created as follows:

1) Business as usual - effort level stays at current effort level (Current)

2) Optimum effort level is reached in the first year (MSY-2020)
3) Optimum effort level is reached in 2024, until that point effort level stays at current level (MSY-2024)
4) Effort level is reduced evenly in first five years and it reaches optimum level in 2024 (MSY-2024 phased)
5) Optimum effort level is reached in 2029, until that point effort level stays at current level (MSY-2029)
6) Effort level is reduced evenly in first ten years and it reaches optimum level in 2029 (MSY-2029 phased)
7) Incentive scheme is introduced. Fishers are offered money to leave the industry. Vessels number is reduced to optimal level and needed number of vessels will be pulled out of the market in first year. Total cost of the scheme is allocated to first year. (Incentive-2020)
8) Incentive scheme is introduced. Fishers are offered money to leave the industry. Vessels number is reduced evenly in first five years and it reaches optimal level in 2024. Costs of the scheme is allocated evenly to the first five years. (Incentive-2024)

4.6 Data

Numbers to represent the EU's fishing industry in Northeast Atlantic were obtained from the annual report of Scientific, Technical and Economic Committee for Fisheries (2018a) and numbers can be seen in table 5.

Table 5: Summary of the STECF Annual Economic Report of EU Fishing Fleet (presented in millions). Data is from 2018 report and represents 2016 numbers. (STECF, 2018a)

Total EU landings in Northeast Atlantic (tonnes)	**3775.5**
Landing value (€)	**4975.2**
Crew wage costs (€)	1517.6
Unpaid labor (€)	158.8
Energy costs (€)	528.5
Repair costs (€)	493.6
Other variable costs (€)	640.7
Other non-variable costs (€)	375.1
Annual depreciation (€)	411.8
Total costs (€)	**4126.1**
Operating profit (€)	**849.1**
Number of EU vessels in the Northeast Atlantic	**26047.0**
Mean price (€/kg)	**1.3**
Average buy-back cost per vessel (€ thousand) (Calvo et al. 2015)	**218.5**

To ensure the validity of the data, the numbers were compared to FAO equivalent numbers. TACs numbers were obtained from the decisions of the Council of the European Union (2016). The yields corresponding of the MSY were obtained from the literature (Merino et al., 2014; ICES, 2013; Guillen et al, 2013).

Average price of the seafood was defined from the STECF report (2018a) by dividing the value of landings by the landing weight in the Northeast Atlantic. Total cost was estimated from the STECF report (2018a) by summing total fishing cost for the EU landings in the Northeast Atlantic. Average buy-back cost per vessel were adapted from Calvo et al. (2015) research.

5 Results

5.1 Management points

Figure 4 presents aggregated fishing data from Northeast Atlantic and it shows the value of landing, operating profit and costs in monetary terms as a function of effort. Figure's effort level is scaled in a way that current fishing effort is set to 1 and effort level decrease towards origin. Effort level defined this way is called relative effort level. Four management points are marked in the figure (Current, Open-access, MSY and MEY) and calculated long-term values of each point are listed in table 6.

The current point represents the state where EU's fishing fleet are in this point in time in the Northeast Atlantic. Currently the profit of the EU's fishing fleet in Northeast Atlantic is €0.85 billion and it is not far away from the open-access equilibrium point since relative effort level that leads to open-access is 1.04. It means that only 4% increase to the current effort level would lead to open-access equilibrium and zero profits.

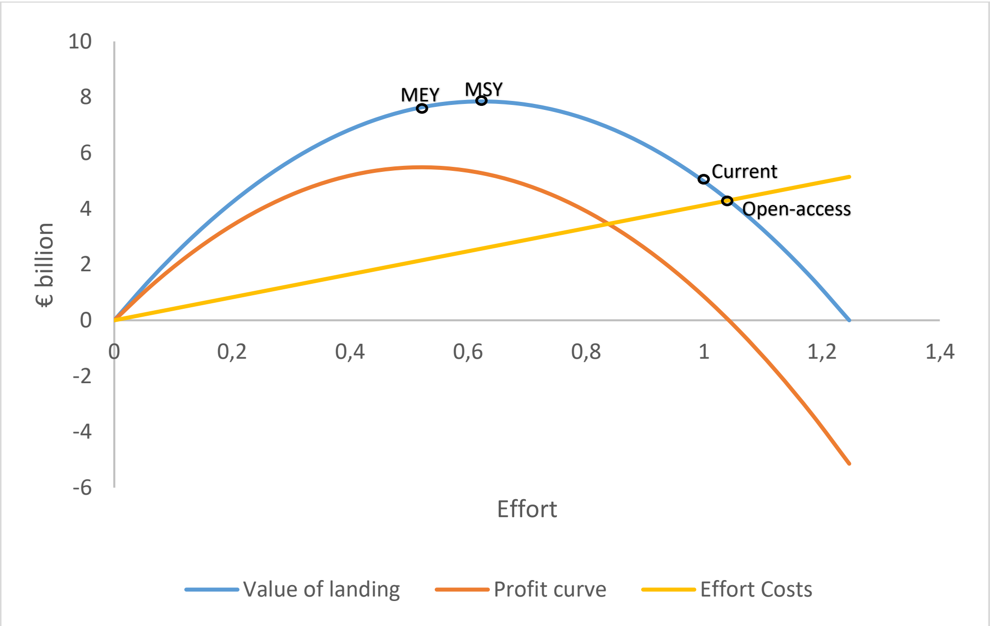

Figure 4: Value of landing, costs and operating profit as a function of effort for the EU fleet in the Northeast Atlantic.

It is easy to make conclusion from the figure 4, that current state of fish stocks in Northeast Atlantic are far away from producing MSY or MEY. In order fish stocks to produce MSY, the relative effort level should be dropped to 0.62, at that effort level the long-term profit would be €5.28 billion. Profits of the stocks are maximized in MEY (€5.49 billion), which is reached in relative effort level 0.52. Difference between MSY and MEY is not huge but still notable, since annual profit in MEY would be €0.21 billion more than in MSY.

Based on result of this study, the EU's fishing fleet would get €4.43 billion more profit if Northeast Atlantic fish stocks were exploited in a way that it is capable of deliver MSY and the gained profits would be even higher if the stocks could deliver MEY. However, effort level should be decreased significantly in order Northeast Atlantic stocks to revive to the MSY level. Effort level should be decreased 38% to reach the effort level that matches the MSY.

Table 6: Landing value, cost, profit and relative effort level for four alternative management schemes. All monetary values are in billion euros.

	Relative effort level	Landing value	Costs	Profit
MEY	0.52	7.64	2.15	5.49
MSY	0.62	7.85	2.57	5.28
Current	1.00	4.98	4.13	0.85
Open-access	1.04	4.30	4.30	0.00

5.2 Rebuilding the stocks

It is undeniable that EU fleet would receive higher profits if all the stocks would be at MSY or MEY. Fishing effort must be reduced below its current state of equilibrium to stocks to recover. Referring to figure 4, moving from current point towards MSY, fish landing should be lower than equilibrium catch for a certain period in order stocks to revive. After the effort level is dropped to match the effort level of MSY, catch could be increased slowly year by year until the MSY is reached. It is impossible to catch MSY immediately, even if the effort level is reduced to match the MSY, since fish stock demand time to reproduce. It depends on each fish's characteristics and the fishing effort, how long it takes to stocks to rebuild.

In figure 5, an example of one pathway to rebuild Northeast Atlantic fish stocks is presented. Fishing effort is reduced to match the relative effort level of MSY within five years and the reduction is evenly distributed over each of the first five years. Graph a) shows the optimal harvesting path towards MSY. In first three years, the effort reduction leads to lower catch but already in fourth year, the catch exceeds the current amount, even though the effort is reduced by 30%. Optimal effort level is reached in fifth year, after that the catch increases slowly until the MSY is reached. Graph b) demonstrates the time that it will take to rebuild the Northeast Atlantic stocks. According to the calculations, stocks can deliver 99% of the MSY at beginning of the 13th year of the rebuilding process.

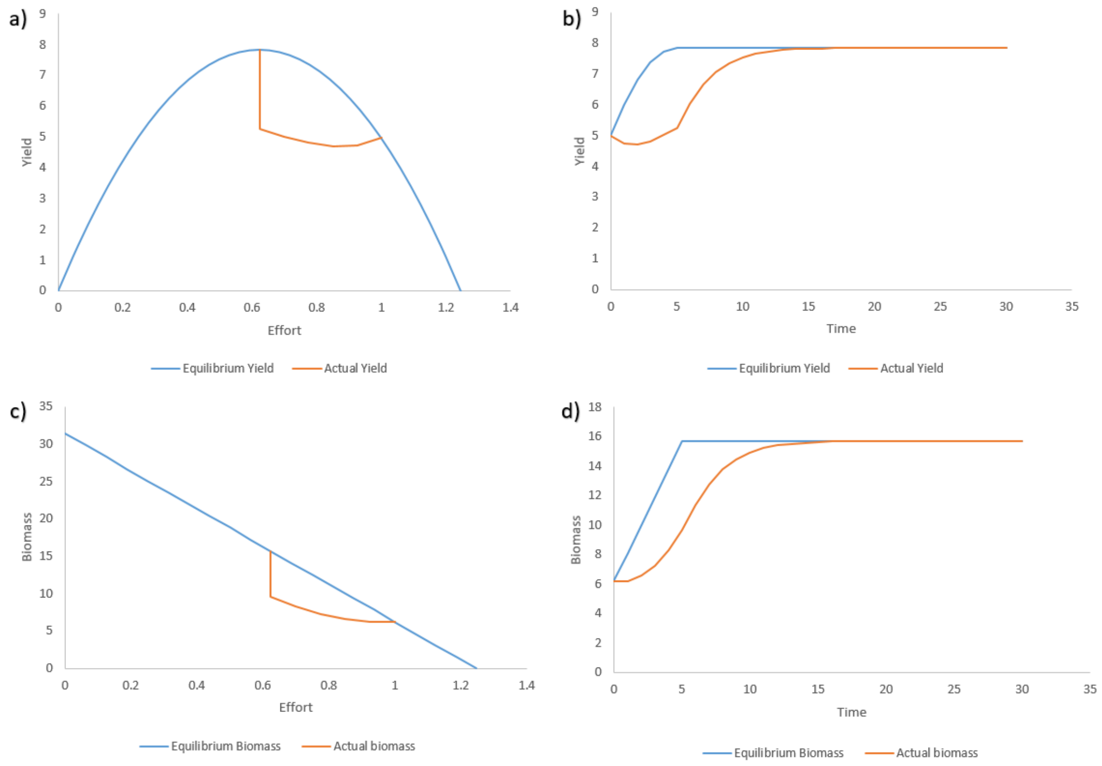

Figure 5: Example of the one rebuilding pathway. Fishing effort is steadily reduced in five years to match the MSY level of effort.

Graphs c) illustrates the biomass change on a function of effort. Effort is reduced to level of MSY in 5 years and biomass starts to grow immediately after reduction of effort. Graph d) shows how many years it will took before biomass reaches the MSY level. The biomass level that can produce MSY is reached at the same time as level of MSY and in that sense; it is obvious that 99% of the MSY biomass level is met after 13th year.

5.3 Optional pathways to rebuild the stocks

In the previous section, one example was provided for the rebuilding pathway towards optimal state of the Northeast Atlantic fish stocks. In this section, four other optional pathways are added into the analysis, which are compared with each other. All management strategies are already presented in the chapter 4. Net present value provides effective tool to compare alternative options, since it takes into account all of the futures profits and discount them into the present value. Discount rate used is 3%. Rebuilding time is also calculated for each alternative pathway.

Figures 6 and 7 present the results of different rebuilding pathways. Highest net present value (€93.04 billion) is gained when optimum effort level is adapted in first year. Second highest net present value (€85.90 billion) is collected when effort level decreases steadily and reaches optimal level in fifth year. The third (MSY-2029-phased) and the fourth (MSY-2024) highest net present value are close together, with only €0.16 billion difference. The smallest net present value (€58.72 billion) is gained when current effort level is kept until 2029 and after that, the effort level is reduced to optimal.

Figure 7 reveals rebuilding times and annual profits for each management strategy. Stocks have fully recovered when maximum annual profit in MSY (€5.28 billion) can be collected. Fastest rebuilding time is on MSY-2020 and MSY-2024-phased, 11 and 13 years, respectively. MSY-2024's rebuilding time is not too far from the first two, since it will take 15 years for MSY-2024 to get stocks to produce MSY. Longest rebuilding time is 21 years and it belongs to management strategy MSY-2029.

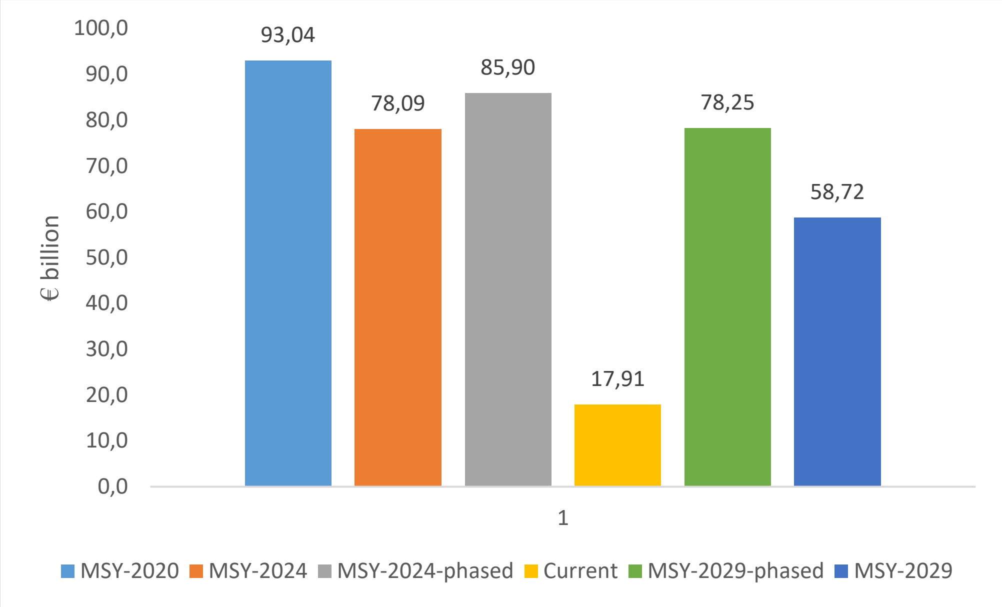

Figure 6: Net present value of different MSY pathways. Period under review 2019-2050.

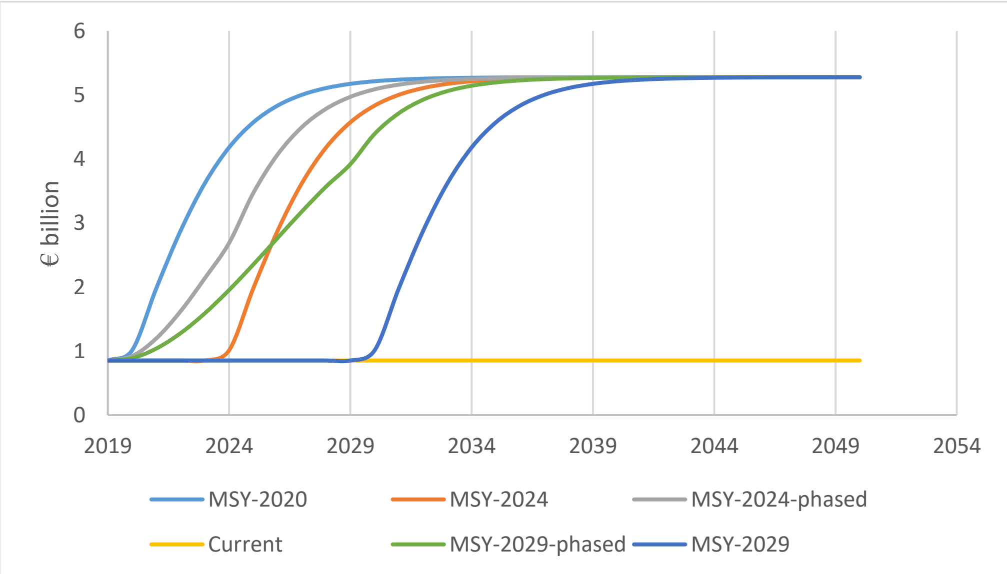

Figure 7: Annual profits and rebuilding time of different MSY pathways.

Management strategies are slightly different compared to each other, but it should be noted, that even if the optimal effort level is reached as late as in 2029, it is still much better than continue on current path. Net present values are multiple times higher in all scenarios, then generated net present value if the Northeast Atlantic fisheries will continue to be fished at current effort level. Generally, the faster the effort level is dropped to the optimal, the faster the stock is rebuilt and higher are the generated net present value. This is true in all other management options except between MSY-2029-phased and MSY-2024. MSY-2029-phased reach the profit level of MSY two years later than MSY-2024, but still its net present value is slightly greater.

5.4 Incentive to leave the industry

Previous parts of this study highlighted the immediate need for improvements of Northeast Atlantic fish stocks. Until this point, the analysis has not offered any actual tools of how the rebuilding process could be done and what are the short-term incentives for the fishers to decrease effort and why they would accept lower profits for certain period of time. These are the important questions because often fishers are in a situation, where they are not able to fish less, since their income level does not allow it and they might have family that have to be supported. Fishermen understand the benefits of rebuilding, but they do not know whether reducing their individual fishing effort would lead to healthier fish stocks or merely increase the catches of others.

Providing incentive to leave the industry could potentially tackle some of the above-mentioned issues and provide effective tool to reduce effort level. This study assumes that every vessel is identical, means that every vessel pulled of the market will reduce effort a same amount. Average incentive to leave the industry per vessel is adapted from the study of Calvo et al. (2015) and value being used is €218.5 thousand per vessel. Currently 26 047 vessels are operating in the Northeast Atlantic which stands for effort level 1. Since MSY effort level is 0.6232, optimal number of vessels should thus be around 38 percent less than it currently is. Number of vessels that corresponds optimal effort level is 16 232, which means that vessels should be reduced by 9815 units. Given the incentive of €218.5 thousand per vessel, total cost would be €2.144 billion.

This study creates two alternative incentive scenarios. In the first scenario, 9815 vessels are agreeing the incentive and leaving the market in first year, meaning that the effort level is optimal immediately in first year, and total cost of the incentive program is allocated to the first year. In the second scenario, incentive program is not that attractive to fishers and optimal number of vessels are reduced from the industry evenly over the first five years. Effort level decreases gradually towards optimal and costs are divided evenly over the first five years.

Figures 8 and 9 illustrate the results of the two incentive scenarios. Figure 8 presents net present values for both incentive scenarios and for comparison, net present value of the current state is represented. Figure 9 shows how the annual profits are developing towards maximum profit level (€5.28 billion). Results shows that net present value is higher in first scenario (€90.96 billion) than in second (€83.93 billion). Result are in line with theoretical pathways towards MSY, which were represented in previous section, since the scenario 1 reaches optimal effort level earlier than scenario 2, and thus net present value is higher with the option 1.

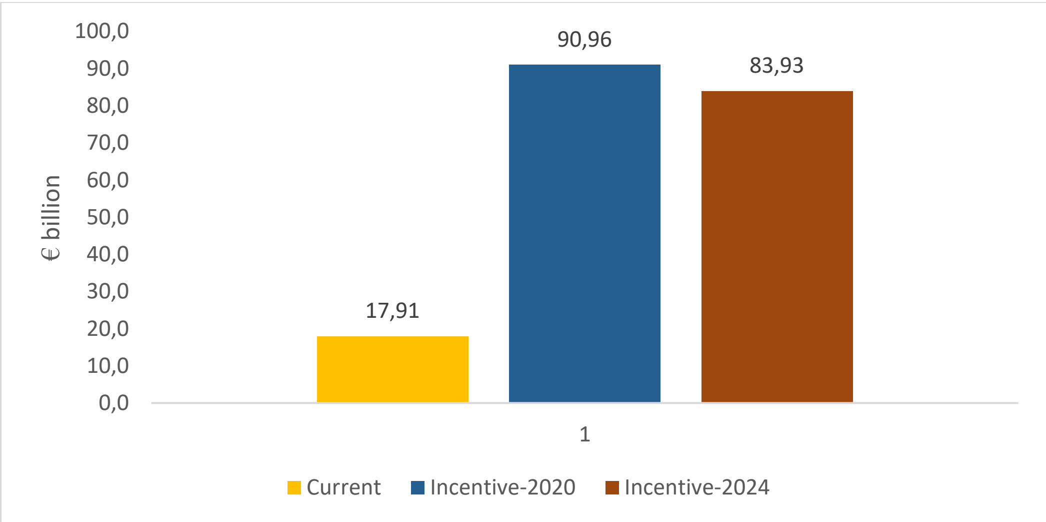

Figure 8: Net present value of the two incentive programs and current state. Period under review 2019-2050.

Annual profit development and rebuilding time can be observed from the figure 9. When all required vessels are bought back in first year, it affects dramatically to the firsts year's profit. In first year, profit is over €1 billion negative due to incentive costs that were allocated to the first year. Profits bounce back to positive after the first year and second year's profit is €1.86 billion. Rebuilding time of the incentive-2020 program is 11 years, in that time annual profit correspond 99 percent of the maximum annual profit. Second program, where vessels are bought in five-year period, can generate positive profit in every year. Profits decreases under the current state in first and second year (first €0.47 billion; second €0.73 billion; current €0.85 billion) but the third year is already more profitable than current situation (€1.09 billion). Rebuilding time of the incentive-2024 program is 13 years.

Both incentive programs could generate more than 4.5 times greater net present value than stocks in their current form could, if the fishing is continued until 2050. Incentive programs could provide effective management tool for control the fish stocks, but the problem is to find adequate funding for the program.

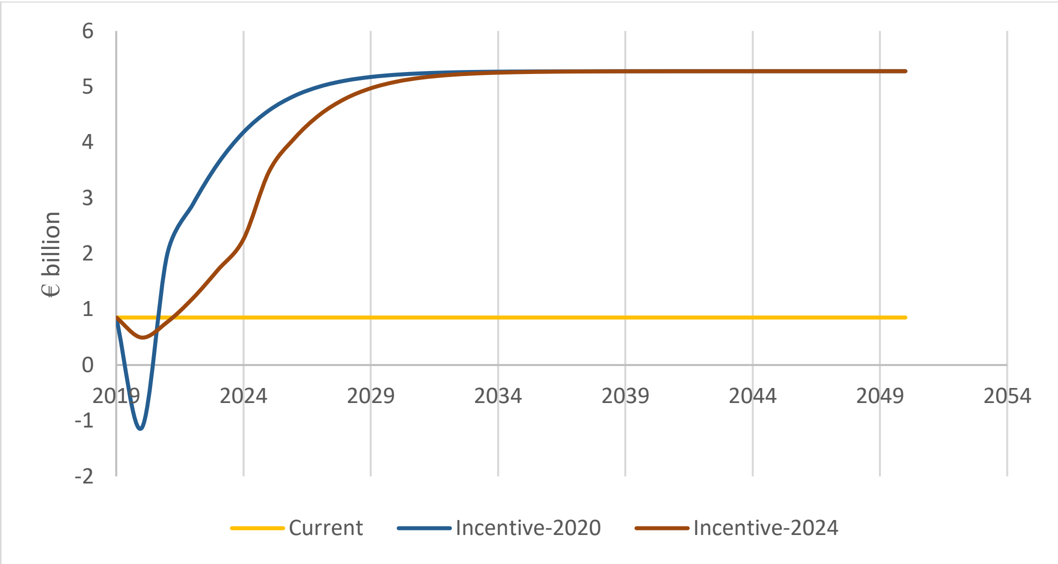

Figure 9: Annual profits of incentive programs.

5.5 Potential value and yield of all seafood production

As stated by the UN, the world population growth is not giving any signs for stabilization, since world populations are estimated to grow from 7.2 billion people to 9.6 billion in 2050 and 10.9 billion in 2100 (Gerland et al. 2014). Such rapid population growth has raised a concern of how to ensure food security in the future and fish-based diet could provide viable option to that problem (Garcia and Rosenberg, 2010; Bene et al., 2015). It is highly unlikely that wild capture could meet the future demand of fish and aquaculture is considered as the only solution to fill the gap between supply and demand of fish in the future (Garcia and Grainger 2005).

When analysing value and production of the seafood, the result will fall short if aquaculture is excluded from the review. Aquaculture production is not restricted by nature's carrying capacity, thus the maximum production level is harder to define. According to STECF economic report of the EU aquaculture sector (STECF, 2018b), member states are expecting on average, that aquaculture sector will grow 39% between 2013 and 2023, which would mean around 3% annual growth. At the same report, five other estimations for aquaculture production growth are shown, which were conducted by European parliament, FAO, OECD and collaboration between Thünen-Institute and Wageningen University – in all these estimations annual growth will fall within the range of zero and four percent.

In this study, different annual growth rates are used for estimating futures aquaculture production in Europe. Selected annual growth rates are following the growth rates introduced in economic report of the EU aquaculture sector (STECF, 2018b) and they are varying between 0 and 5%. Annual growth rate might be hard to understand but with 1% growth per year, aquaculture production would be one third larger in 2050 compared today. Five percent annual growth rate would mean, that aquaculture production would be over four times greater in 2050 than currently and that represent highly ambitious goal in this study.

Figures 10 and 11 are visualizing the potential of Northeast Atlantic seafood production. Figure 10 shows how large quantity of seafood could potentially be gained from the wild capture and aquaculture with in a next 30 years. Figure 11 presents the potential value of the wild capture and aquaculture seafood in Northeast Atlantic. In both pictures, it is assumed that optimal effort level of wild capture is reached after 5 years.

Figure 10 illustrate that Northeast Atlantic seafood production's long-term equilibrium state is 7.06 million tonnes, assuming there will be no growth in aquaculture sector in the future. If aquaculture sector will face 1% annual growth, total quantity of seafood would be 7.46 million tonnes. With growth rates 3 and 5%, quantity would be 8.72 and 10.98 million tonnes, respectively.

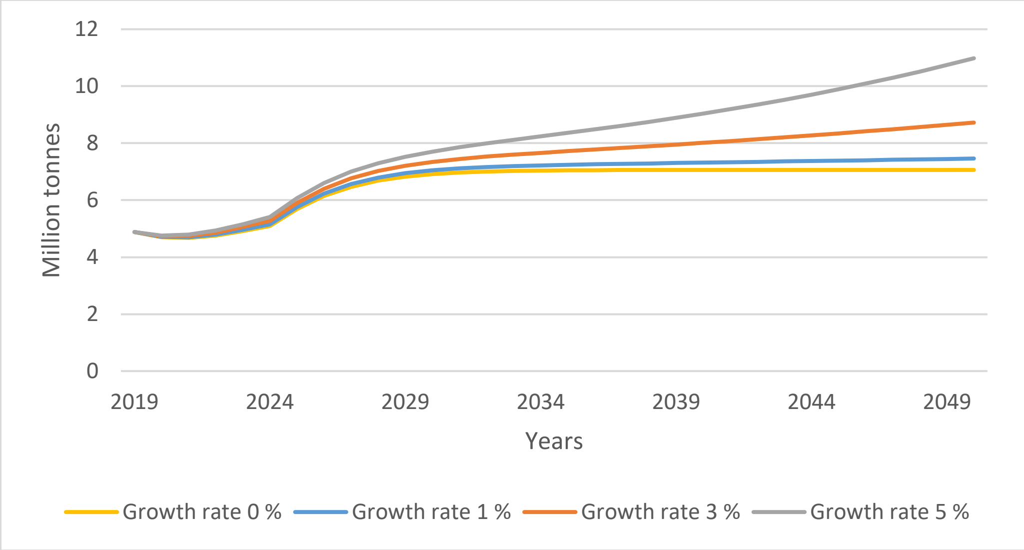

Figure 10: Potential production of total seafood in EU (wild capture and aquaculture).

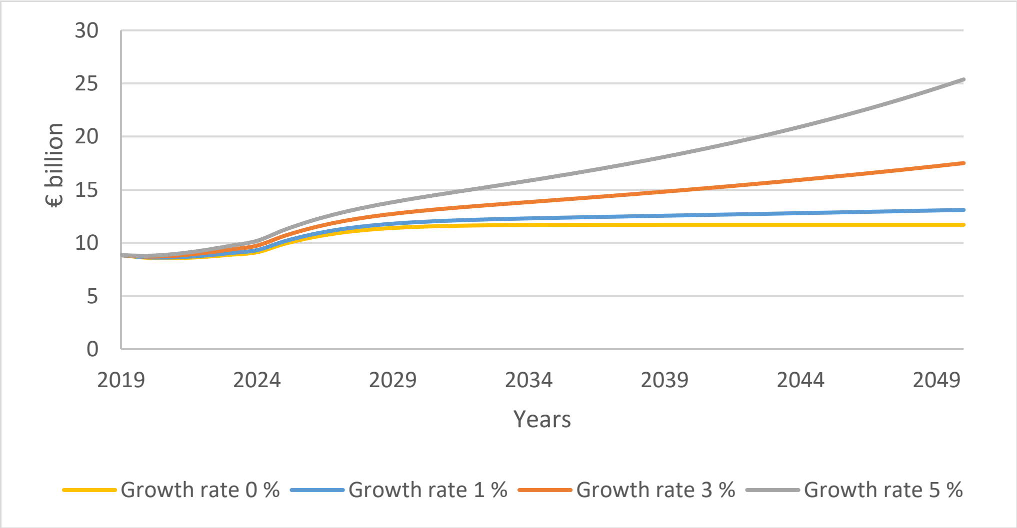

Figure 11: Potential value of total seafood production in EU (wild capture and aquaculture).

Figure 11 provides illustration of development of the potential landing value of the wild capture and aquaculture. Dispersion of the different estimations is greater with value than in case of quantity. Landing value would be €11.71 billion when aquaculture stays at current level and €13.10 billion if annual growth rate of aquaculture is 1 %. Landing value grows to €17.50 billion when three percent growth is being observed and €25.38 billion if annual growth rate climbs to 5%.

6 Discussion

European Commission admits in the initiative that propose new regulations for fisheries management in EU waters (European Commission, 2015), that changes must be introduced for multi-annual plans if fish stocks are to be revived to a level capable of delivering MSY, which is the final objective of the common fisheries policy (CFP). In that paper, European Commission state that current actions have been inadequate since majority of the fish stocks are overfished. According to the report, fishing industry and related industries do not reach their full potential in terms of economics, environmental and social welfare because stocks are overexploited.

Similar findings were made in this study than European Commission made in their above-mentioned initiative. The results of this study show that EU fleet in Northeast Atlantic are still far away from reaching level where MSY or MEY would be delivered and reduction in fishing effort is inevitable action in order to reach the objective.

According to this study, effort level should be dropped by 38% in order to achieve MSY in long run, and by 48% to match the level of the MEY. Rebuilding the stocks to MSY by effort reduction, would lift generated landing value by €2.87 billion (€2.66 billion in MEY) while the fishing costs would drop by €1.56 billion (€1.98 billion in MEY). Rebuilding the fishery to a level where all the stocks are able to produce MSY or MEY, would increase profits by increasing landing value and decreasing costs. If effort level were placed to match the MEY effort level, the operating profit would be €5.49 billion, which means that profit would increase €4.64 billion compared to current situation. If effort were placed to match the MSY effort level, the operating profit would be €5.28 billion, which means that profit would be €4.43 billion more than currently. It is noteworthy how large proportion of the increased profit is due to cost reduction and how much due to stock rebuild. The ratio is closer to 50/50 in MEY, where 57% of the gained profit is due to stock rebuild and 43% from cost reduction. In MSY, 65% of the newly generated profit is coming from increased landing and 35% from cost reduction.

At current position, EU fleet in Northeast Atlantic are generating €0.85 billion profit (landing value €4.98 billion, costs €4.13 billion). In the current situation, the

Northeast Atlantic fish stocks are much closer to be at open-access equilibrium point than reaching MSY or MEY (see figure 4). Profits generated from the Northeast Atlantic fishery would decrease to zero if effort level would increase by 4%, in that point, landing value and costs would both be €4.30 billion. The situation can be seen as highly alarming, considering how much closer the current point is to open-access than MSY.

In this study, several management strategies for rebuilding the Northeast Atlantic stocks were introduced. Rebuilding time and net present value were calculated for each management strategy. In calculations, stocks were fully recovered, when they could provide 99% of the full potential and time period for net present value calculations were 31 years (2019-2050) with 3% interest rate. The results clearly address that it is preferable to decrease effort level as soon as possible to match the effort level of MSY. The sooner the optimum effort level is reached, the shorter is the rebuilding time and the higher is the net present value in next 31 years. Only exception of this rule is MSY-2029-phased because its net present value is greater than MSY-2024 even though the rebuilding time is longer.

There are two reasons why it is more profitable to decrease effort level fast compared to rebuilding stocks in longer period. Firstly, it instantly reduces costs, which leads to increased profits already in first year, even though the yield is lower than currently in first two years. Secondly, the stocks can revive only when effort level is reduced, so it is optimal to achieve MSY effort level fast, in order to gain benefits from the growing stocks earlier. The combination of those two factors are generating the incentive to lower the effort level sooner. In turn, the rapid decline in the effort level is generating trade-offs, since it would mean that large number of former fishers would be forced to find new earning opportunities from somewhere else. However, the problem is not necessarily that massive, because it can be assumed that new jobs will eventually be created in different part of the fish supply chain (for example cutting and packaging) because of the growing catch. However, the impacts could be dramatic in the short term.

This study follows the same pattern as study contacted by Guillen et al. (2016). One aim of the study was to observe at which direction has the state of the Northeast Atlantic fish stocks shifted over the past three years. Table 7 provides results of this study and Guillen et al. (2016) study in a comparable format. Table 7a shows the results of Guillen et al. (2016) and table 7b presents the result of this study.

Table 7a&b: Comparison of the results. All monetary values are in billion euros.

a)

	Relative effort level	Landing value	Costs	Profit
MEY	0.50	7.12	2.21	4.91
MSY	0.62	7.38	2.73	4.64
Current	1.00	4.51	4.41	0.10
Open-access	1.005	4.43	4.43	0.00

b)

	Relative effort level	Landing value	Costs	Profit
MEY	0.52	7.64	2.15	5.49
MSY	0.62	7.85	2.57	5.28
Current	1.00	4.98	4.13	0.85
Open-access	1.04	4.30	4.30	0.00

It can be noted from the table 7 a and b, that the state of the Northeast Atlantic stocks has moved slightly towards MSY in past three years, since difference between current point and open-access point has grown slightly (from 0.5% to 4%). However, the distance between current point and MSY (or MEY) point are almost the same in both studies. Northeast Atlantic fish stocks could now provide more economic wealth than at the time when Guillen et al. (2016) conducted their study. Profits have grown in all three management option points and potential profit in MSY point is €0.64 billion more than three years ago. Profits in current point has grown significantly since Guillen et al. (2016) study, currently EU fleet are earning €0.75 billion more from the Northeast Atlantic than three years ago.

Profits have increased and it is due to lower costs and higher landing value. In three years, costs have dropped from €4.41 billion to €4.13 billion and landing value increased from €4.51 billion to €4.98 billion. However, costs and landing value have not changed in same proportion. Major part of the profit increase is coming from landing value, for example in MSY, 75% of the profit growth comes from increased landing value. The ratio is more even in current point but still landing value is dominating with 63% of the profit growth.

There are some simplifications in the model, which should be highlighted. Firstly, it is not ecologically possible to maintain all fish stocks at a level of MSY at the same time (Ye et al., 2013). Actual collective maximum production of the fish stocks may be lower than sum of the species-specific MSYs. That is because of the trophic dynamics of the ecosystem, which means that the recovery of some fish stocks could adversely affect other stocks, so that they no longer can produce MSY. Secondly, approach of this study takes into account only commercially fished stocks and exclude stocks that are not fished at all or fished recreationally. Thirdly, this study does not include externalities into the analysis. Economic valuation of externalities falls outside of the scope of this study because most of them are non-market and for that reason, valuing them would have required more time and resources that was in use. Fourthly, for simplification, this study calculates only the boat owner's profits and overlooks the added value of which this economic activity is generating to the whole society. Calculating cross value added would generate a better overall picture of the situation because it would sum up e.g. paid taxes, crew remuneration and interests on loans.

By now, the ecosystem service concept has been widely accepted and adapted in different field of a science. However, process of applying the ecosystem service concept to the marine research has been relatively slow, mainly because of data scarcity. Marine ecosystem service studies represent only 9% of the all ecosystem service literature, even though marines cover more than 70% of the earth's surface. Clear difference is revealed when marine ecosystem service research is compared to the terrestrial counterparts. In 2015, 400 articles with title of 'ecosystem services' were related to terrestrial field and only bit over 50 were related to marines. In that sense, more research is needed on marine ecosystem services and their benefits if the knowledge cap between terrestrial and marine ecosystem services is wanted to be closed. (Townsend et al., 2018)

European Marine Board (Austen et al., 2019) state that valuation of the benefits from marine ecosystem services can support policy development and sustainable blue growth as well as arouse debate on the importance of the marine environment.

European Marine Board (Austen et al., 2019) recommends that ecosystem valuations should be better included into marine management decision models, since right now ecosystem valuation are only rarely exploited in marine policy decisions. European Marine Board (Austen et al., 2019) published recommendations on where researchers should focus on in order to make their work better suited for decision-making process. Firstly, they recommend that ecosystem frameworks should be harmonized because current situation, where multiple classification systems and frameworks exists, complicates comparability of the results. Secondly, clear indicators between ecosystem functions and ecosystem services and benefits need to be identified in order to include them into already existing monitoring programs. Thirdly, European Marine Board (Austen et al., 2019) advice that open database should be created, where data and the results of marine ecosystem service valuation studies are stored. Open database would improve comparability and usability of the results of the valuation studies. Researchers should work with these issues and try to come up with adequate solutions in order valuation of marine ecosystem service to be better considered for decision-making process.

7 Conclusion

This thesis has estimated the value of the European Union's maximal potential fish landing in the Northeast Atlantic and compared different rebuilding pathways for the stocks. This work is part of a bigger entity where European Union strives to estimate the total value of marine ecosystem services. This study highlights the importance of stocks recovery and underlines the economic incentive to do so.

EU's maximum potential fish landing in Northeast Atlantic was calculated in an imaginary situation where all stocks could produce MSY at the same time. Growth potential of EU's fisheries sector was obtained by comparing fishers' current profit with the theoretical maximum profit. Stocks must be rebuilt in order them to produce MSY. Different rebuilding pathways were defined, and rebuilding time and net present value were used to compare different options. Created model is based on Gordon-Schaefer bioeconomic model.

Results of the study indicates that EU's fishery sector has much to improve. Northeast-Atlantic fish stocks are overfished, and EU's current position is much closer to open-access equilibrium point than MSY or MEY point. Reductions in fishing effort should be implemented in order stocks to revive. Achieving MSY in the long term, fishing effort should be reduced by 38% from the current state, and to reach MEY, fishing effort should be reduced by 48%.

EU fleet are currently making €0.85 billion profit per year. Annual profit could increase, as high as, €5.28 billion per year if all stocks could provide MSY. Maximum sustainable profit is achieved when stocks are harvested to a point where MEY is provided, and profits in MEY would be €5.49 billion.

Fish stocks rebuilding pathways towards MSY was arranged according to how quickly the optimum fishing effort is achieved. According to findings, fishing effort should be lowered to optimal as fast as possible, since then net present value is at maximum and rebuilding time is the shortest. The results, in this respect, should be processed further because the model does not take account other costs that are associated to reduction of fishing effort, such as higher unemployment rates.

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Annexes 1

Formulas to calculate required parameters to form Gordon-Schaefer model:

1) $h_{msy} = \frac{RK}{4} \longrightarrow K = \frac{4h_{msy}}{R}$

2) $E_{msy} = \frac{R}{2q} \longrightarrow \quad q = \frac{R}{2E_{msy}}$

3) $h_{current} = qEK - \frac{q^2KE^2}{R}$

Place the equations 1 and 2 to the equation 3 and solve R.

4) $h_{current} = \left[\frac{R}{2E_{msy}} * \frac{4h_{msy}}{R} * E_{current}\right] - \frac{\left[\frac{R}{2E_{msy}}\right]^2 * \frac{4h_{msy}}{R} * E_{current}^2}{R}$

5) $h_{current} = \frac{4h_{msy}E_{current}}{2E_{msy}} - \frac{R^2 4h_{msy}E_{current}^2}{4E_{msy}^2}$

6) $\frac{R^2 h_{msy}E_{current}^2}{E_{msy}^2} = \frac{2h_{msy}E_{current}}{E_{msy}} - h_{current}$

7) $R = \sqrt{\frac{2E_{msy}}{E_{current}} - \frac{h_{current}E_{msy}^2}{h_{msy}E_{current}^2}}$